

AD-A045 874

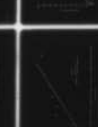
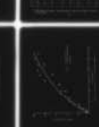
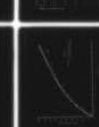
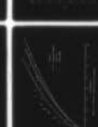
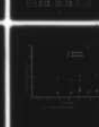
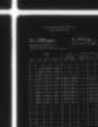
ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY ABERDEEN PROV--ETC F/G 19/1  
AN ANALYSIS OF THE SMOKE CLOUD DATA FROM THE AUGUST, 1975 JEFFE--ETC(U)  
SEP 77 T J DOLCE, D F METZ

UNCLASSIFIED

AMSAA-TR-201

NL

1 OF 2  
ADA045874



ADA 045874

# AMSA

TECHNICAL REPORT NO. 103

AN ANALYSIS OF THE TACTICAL VALUE OF THE  
M107, 1975-1976 FIELD TEST DATA

J. A. BAKER  
R. E. BERRY

SEPTEMBER 1977

DDC  
RECEIVED  
SEP 21 1977  
DISTRIBUTION

APPROVED FOR PUBLIC RELEASE  
DISTRIBUTION UNLIMITED

U.S. ARMY MATERIAL SYSTEMS ANALYSIS ACTIVITY  
AMERICA TOWNS GREENE BARRACKS

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM												
1. REPORT NUMBER <b>AMSAA-TR-201</b>	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER												
4. TITLE (and Subtitle) <b>An Analysis of the Smoke Cloud Data from the August, 1975 Jefferson Proving Ground Smoke Test.</b>	5. TYPE OF REPORT & PERIOD COVERED													
7. AUTHOR(s) <b>T. J. Dolce D. F. Metz</b>	6. PERFORMING ORG. REPORT NUMBER													
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Materiel Systems Analysis Activity Aberdeen Proving Ground, MD 21005	8. CONTRACT OR GRANT NUMBER(s)													
11. CONTROLLING OFFICE NAME AND ADDRESS Commander, US Army Materiel Development and Readiness Command, 5001 Eisenhower Avenue, Alexandria, VA 22333	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DA Project No. <b>1R765796M541</b>													
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	12. REPORT DATE <b>11 Sept 1977</b>													
	13. NUMBER OF PAGES <b>108</b>													
	15. SECURITY CLASS. (of this report) <b>UNCLASSIFIED</b>													
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.														
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)  DDC NOV 2 1977 F														
18. SUPPLEMENTARY NOTES														
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) <table border="0"> <tr> <td>smoke</td> <td>smoke modelling</td> <td>105mm howitzer</td> </tr> <tr> <td>smoke munitions</td> <td>60mm mortar</td> <td>155mm howitzer</td> </tr> <tr> <td>white phosphorus</td> <td>81mm mortar</td> <td></td> </tr> <tr> <td>hexachloroethane</td> <td>4.2" mortar</td> <td></td> </tr> </table>			smoke	smoke modelling	105mm howitzer	smoke munitions	60mm mortar	155mm howitzer	white phosphorus	81mm mortar		hexachloroethane	4.2" mortar	
smoke	smoke modelling	105mm howitzer												
smoke munitions	60mm mortar	155mm howitzer												
white phosphorus	81mm mortar													
hexachloroethane	4.2" mortar													
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) <p>In order to gather data on smoke cloud growth and characteristics, a test of artillery and mortar smoke munitions was conducted at the Jefferson Proving Ground, Indiana, on 19-21 August 1975. Ten rounds of each of the following WP and HC smoke munitions were dynamically fired in single-round fire missions: 155mm M110 WP; 105mm M60 WP; 4.2" M328 WP; 81mm M375 WP; 60mm M302 WP; 155mm M116 HC; 105mm M84 HC. The series also included a static firing of one round of each of these munitions.</p> <p style="text-align: right;">(See Reverse)</p>														

DD FORM 1 JAN 73 1473

EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

403910



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

Data extraction, discussed in Section 2, was limited to meteorological data and to 16mm films of the clouds from three ground locations, as shown in Figure 1. Measures of cloud growth and other cloud characteristics were extracted from the films.

The data analysis, presented in Section 3, is to support the JTCC/ME Smoke Obscuration Model. It is therefore restricted to: cloud dimensions at early times; rate of rise of the WP plume. The time period of each analysis is limited by the filming time of each fire mission.

ACCESSION for		White Section <input checked="" type="checkbox"/>
NTIS		Buff Section <input type="checkbox"/>
DOC		
MANNOVATED		
1 ST 102 101		
BY DISTRIBUTION/INVENTORY CODES		
D.		
A	23	68



#### ACKNOWLEDGMENTS

The authors acknowledge Mr. Mike Carroll and Mr. Mark Kronman who assisted in the analysis of the JPG test data.

Next page is blank

# TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS. . . . .	3
LIST OF FIGURES . . . . .	7
LIST OF TABLES. . . . .	9
1. INTRODUCTION. . . . .	11
2. DATA EXTRACTION . . . . .	11
2.1 Meteorological Conditions. . . . .	11
2.2 WP and HC Cloud Characteristics. . . . .	15
3. APPLICATION OF MEASURED DATA. . . . .	15
3.1 Source Description . . . . .	19
3.2 WP Plume Rise Models . . . . .	19
3.3 HC Cloud Rise Models . . . . .	21
3.4 Static Firings . . . . .	21
4. CONCLUSIONS . . . . .	22
REFERENCES. . . . .	23
APPENDIX A. Cloud Data Sheets. . . . .	25
APPENDIX B. Graphs . . . . .	73
APPENDIX C. Joules Cloud Rise Model. . . . .	101
DISTRIBUTION LIST . . . . .	107

Next page is blank

# LIST OF FIGURES

	Page
Figure 1: Diagram of Test Setup. . . . .	12
Figure 2: Summary of WP Cloud Characteristics. . . . .	16
Figure 3: Summary of HC Cloud Characteristics. . . . .	17
Figure 4: Source Sigmas versus WP Fill Weights . . . . .	20
Figure 5: Source Discription, 155mm WP . . . . .	73
Figure 6: Source Discription, 4.2" WP. . . . .	74
Figure 7: Source Description, 105mm WP . . . . .	75
Figure 8: Source Description, 81mm WP. . . . .	76
Figure 9: Source Description, 60mm WP. . . . .	77
Figure 10: Plume Rise, 155mm WP, Pasquill Category A. . . . .	78
Figure 11: Plume Rise, 155mm WP, Pasquill Category B. . . . .	79
Figure 12: Plume Rise, 155mm WP, Pasquill Category C. . . . .	80
Figure 13: Plume Rise, 4.2" WP, Pasquill Category A . . . . .	81
Figure 14: Plume Rise, 4.2" WP, Pasquill Category B . . . . .	82
Figure 15: Plume Rise, 4.2" WP, Pasquill Category C . . . . .	83
Figure 16: Plume Rise, 105mm WP, Pasquill Category A. . . . .	84
Figure 17: Plume Rise, 105mm WP, Pasquill Category B. . . . .	85
Figure 18: Plume Rise, 105mm WP, Pasquill Category C. . . . .	86
Figure 19: Plume Rise, 81mm WP, Pasquill Category A . . . . .	87
Figure 20: Plume Rise, 81mm WP, Pasquill Category B . . . . .	88
Figure 21: Plume Rise, 60mm WP, Pasquill Category B . . . . .	89
Figure 22: Downwind Cloud, 155mm HC, Pasquill Category B. . . .	90



# LIST OF FIGURES (CONT)

	Page
Figure 23: Downwind Cloud, 155mm HC, Pasquill Category C . . . .	91
Figure 24: Downwind Cloud, 105mm HC, Pasquill Category A . . . .	92
Figure 25: Downwind Cloud, 105mm HC, Pasquill Category B . . . .	93
Figure 26: Plume Rise, 4.2" WP, Pasquill Category C, Static Firing. . . . .	94
Figure 27: Plume Rise, 105mm WP, Pasquill Category C, Static Firing. . . . .	95
Figure 28: Plume Rise, 81mm WP, Pasquill Category C, Static Firing. . . . .	96
Figure 29: Plume Rise, 60mm WP, Pasquill Category C, Static Firing. . . . .	97
Figure 30: Downwind Cloud, 155mm HC, Pasquill Category C Static Firing. . . . .	98

LIST OF TABLES

	Page
TABLE 1: JPG Meteorological Data - Surface Readings. . . . .	13
TABLE 2: AMSAA Meteorological Data - Surface Readings. . . . .	14
TABLE 3: Parameters for Cloud Rise Functions. . . . .	18

Next page is blank

AN ANALYSIS OF THE SMOKE CLOUD DATA FROM THE AUGUST 1975  
JEFFERSON PROVING GROUND SMOKE TEST

1. INTRODUCTION

To gather data on smoke cloud growth and characteristics, a test of artillery and mortar smoke munitions was conducted at the Jefferson Proving Ground, Indiana, on 19-21 August 1975.<sup>(1)</sup> Ten rounds of each of the following WP and HC smoke munitions were dynamically fired in single-round fire missions: 155mm M110 WP; 105mm M60 WP; 4.2-inch M328 WP; 81mm M375 WP; 60mm M302 WP; 155mm M116 HC; 105mm M84 HC. The series also included a static firing of one round of each of these munitions.

Data extraction, discussed in Section 2, was limited to meteorological data and to 16mm films of the clouds from three ground locations, as shown in Figure 1. Measures of cloud growth and other cloud characteristics were extracted from the films.

The data analysis, presented in Section 3, is to support the JTTCG/ME Smoke Obscuration Model.<sup>(2)</sup> It is therefore restricted to: cloud dimensions at early times; rate of rise of the WP plume. The time period of each analysis is limited by the filming time of each fire mission.

2. DATA EXTRACTION

Extensive measurements were made of WP and HC cloud characteristics from the ground-based 16mm films. The graduated reference markers in the field appeared with the clouds in the films, and provided a scale with which to extract linear dimensions. Time estimates were based on the filming speed of 24 frames/sec. An adjustment was applied to the measurements to account for the angle between the film plane\* and the direction of cloud travel. This adjustment has been made to the data reported in Appendix A. The location of the smoke sources relative to the impact area were derived by use of the grid markings on the ground, which appeared in the 16mm photographic coverage from helicopters.

2.1 Meteorological Conditions

The meteorological conditions of wind, atmospheric stability, and relative humidity are crucial to the growth and transport of a

---

\*Cameras were in a fixed orientation



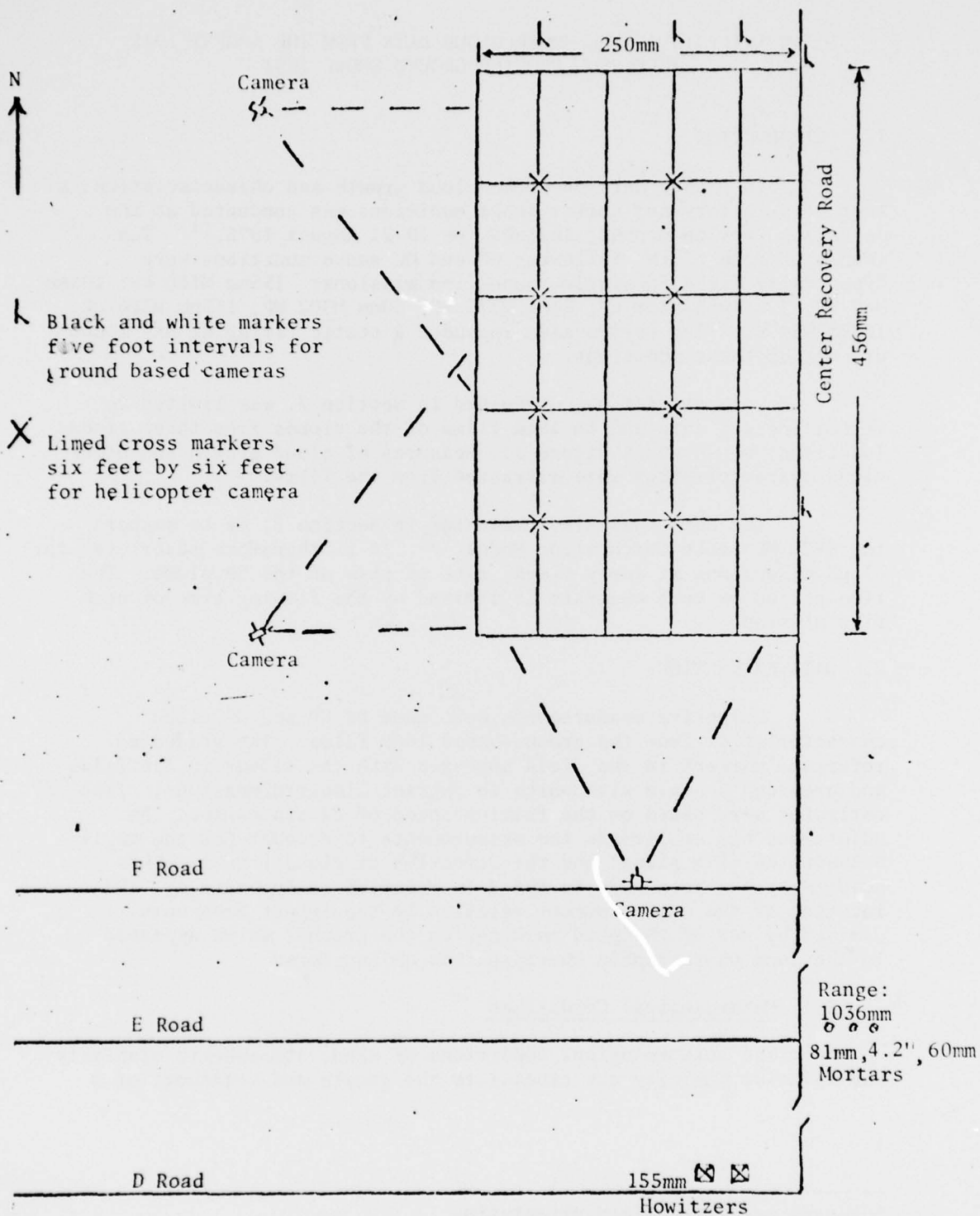


Figure 1. Diagram of Test Setup (1)

TABLE 1. JPG METEOROLOGICAL DATA - SURFACE READINGS (1)

Time		Wind Data		Bar. Pres. Corrected	Temp MM	Wet	RH	Den.	Visibility	Precip.	Weather	Cloud	
Dir.	Vel. (Knots)	Dir.	Vel. (Knots)									Coverage	Base
Date: 19 Aug 75													
0200	150	3		29.150	71.0		95	96.1	100% cld cover less than 1/2 mi.	None	Hazy-cldy	Ovc 7500'M	
0900	270	0-2		29.170	72.0		91	95.9	"	Trace	"	Ovc 4000'E	
1000	120	2		29.180	73.0		91	95.7	100% cld cover less than 3/4 mi.	None	"	Bkn 15000'	
1100	255	4		29.180	79.0		75	94.6	No clouds, 2 mi.	None	Sunny	Unlimited	
1200	280	2-4		29.178	82.0		69	94.1	Set clds, 3 mi. 50%	None	Hazy-cldy	Bkn 8000'	
1300	330	2		29.167	82.0		65	94.1	"	None	Hazy-PC	Bkn 8000'	
1400	270	3		29.150	85.0		57	93.7	Cldy 80%, 5 mi.	None	Cldy	Bkn 5000'	
1500	Calm	Calm		29.140	84.0		62	93.7	Cldy 90%, 4 mi.	Trace	Ptly Cldy	Bkn 4500'	
1600	320	2		29.130	84.0		62	93.7	Cldy 90%, 4 mi.	None	"	Bkn 4500'	
Date: 20 Aug 75													
0600	90	6		29.242	72.0		91	95.1	No clouds, fog, 1/2 mile	None	Humid	Unlimited	
0900	95	6		29.260	75.0		82	95.8	25% cumulus, 1 mi.	None	"	Unlimited	
1000	95	2		29.265	77.0		82	95.3	10% cumulus, 1 1/2 mile	None	"	Unlimited	
1100	85	2		29.275	84.0		66	94.0	30% cumulus, 2 mi.	None	PC, humid	Unlimited	
1200	180	3		29.260	83.0		62	94.3	30% cumulus, 2 1/2 mile	None	"	Set 15000'	
1300	250	4-8		29.258	86.0		57	93.7	50% cover, 2 1/2 mi.	None	"	Set 15000'	
1400	090	6		29.250	86.0		53	93.7	75% cover, 2 1/2 mi.	None	"	Bkn 10000'	
1500	180	2-6		29.230	87.0		54	93.5	75% cover, 2 1/2 mi.	None	Ptly Cldy	Set 10000'	
Date: 21 Aug 75													
0300	190	5-9		29.285	75.0	87	95.9	No clds, 1/2 mile	None	None	Clear	Haze 20000'	
0900	210	4-10		29.270	79.0	87	94.9	"	"	None	Clear	Haze 20000'	
1000	210	6-13		29.260	82.0	65	94.4	"	1 1/2 mile	None	Clear	Unlimited	
1100	210	5-12		29.255	85.0	63	93.8	"	3 mile	None	Clear	Unlimited	
1200	220	6-15		29.268	87.0	55	93.5	30% cld cumulus, 3 mi.	None	None	PC	Set 15000'E	
1300	245	8-14		29.260	89.0	55	93.0	50% cld cumulus, 3 mi.	None	None	Cldy	Bkn 15000'E	
1400	250	12-14		29.240	90.0	49	92.8	"	"	None	Cldy	Bkn 15000'E	
1500	260	8-12		29.220	90.0	52	92.8	"	"	None	Cldy	Bkn 15000'E	

TABLE 2. AMSAA METEOROLOGICAL DATA - SURFACE READINGS (1)

Time	Wind Data		Temp C		Dry	Wet	Ground Surface
	Dir.	Vel. (Knots)	Low	High			
Date: 19 Aug 75 - JPC Thermometers							
1412	North	2	27.1	26.6	27.8	24.7	31.4
1535	NW	2	28.7	27.9	28.3	24.4	31.0
1603	NW	3-4	26.0	24.4	25.0	23.1	25.0
1645	NW	3-4	24.6	23.8	27.3	24.2	
Date: 20 Aug 75 - AMSAA Thermometers							
1027	SSE	2-5	26.7	28.2	27.4	24.5	31.9
1103	SSE	5-1	27.4	29.4	28.2	23.9	34.8
1140	SSE	3-4	28.2	30.1	29.2	33.8	35.3
1155	NNW	0-1	29.2	31.2	29.8	23.2	36.6
1252	E	2	30.0	32.0	31.2	25.7	37.7
1318	N	1-2	30.1	32.6			37.8
1355	NW	1-2.4	31.0	32.6			38.4
1430	SE	4-7	29.5	30.8			33.2
1500	NE	4-6	30.2	31.7	30.8	25.0	36.2
1530	NE	3-5	31.8	33.3			36.0
1600	NE	5-6	30.0	31.7	30.6	24.7	34.7
1635	NE	1.2	29.8	31.7			33.2
1705	SE	5-6	29.7	30.9	29.7	24.7	31.9
1735	NE	2-3	28.7	30.2			29.8
1800	E	3	28.4	29.9			28.6
1825	SE	2.2-2.6	27.0	28.4	28.1	24.3	27.5
Date: 21 Aug 75 - AMSAA Thermometers							
0930	SW	6-8	27.4	28.0	28.9	29.7	28.6
1030	SW	6-8	29.2	29.8	30.1	24.8	31.6
1115	SW	6-8	30.2	30.2	30.8	24.8	33.3
1135	SW	6-8	31.0	31.1	32.0	25.0	34.4
1215	SW	2-3	29.8	30.8	30.9	24.7	31.7
1255	SW	4-8	30.7	31.8			34.5
1328	SW	4-6	32.0	32.7	32.6	25.0	34.5
1355	WSW	4-6	32.0	32.6			35.3
1430	NNW	5-8	32.7	33.0	32.6	24.7	35.1
1500	WSW	4-6	31.8	32.3			34.0
1530	WSW	4-8	32.5	32.9	32.3	24.5	33.3
1555	WSW	2-4	31.8	32.7	32.0	25.0	33.2
1635	WSW	3-6	31.2	32.0	32.6	24.8	32.2
1710	WSW	2-4	30.9	31.8			31.2
1733	NNW	2-3	30.0	31.0	31.1	24.7	29.9



smoke cloud. The meteorological data gathered during the JPG test are presented in Tables 1 and 2, and may be related to the individual cloud data records in Appendix A.

An assessment was made of the Pasquill category of atmospheric stability for each fire mission. Pasquill categories of atmospheric stability<sup>(4)</sup> are identified by percent cloud cover and wind speed. The parameters defining each category may be used to predict the growth of a smoke cloud with a Gaussian distribution of mass. Small corrections to these groupings of the cloud measurements were made by comparing the measured heights of the WP plume centroid versus time for each munition. The need for such an adjustment probably reflects short-lived, localized variations in the meteorological conditions during the cloud development.

## 2.2 WP and HC Cloud Characteristics

A summary of WP and HC cloud characteristics for which measurements were made is given in Figures 2 and 3, respectively. This reflects the difference in nature of the WP and HC sources: conventional WP is a bursting munition which exhibits a pillaring effect due to the high heat flux generated by the rapid burning of the WP; HC burns in its component canisters over a 2 to 2.5 minute period. The clouds from the individual canisters quickly merge to form a single cloud which generally has the approximate shape of a right angle triangle. Because of its far simpler shape, fewer measurements were required of the HC clouds than of the WP clouds at each time. The measured cloud dimensions would allow a rough picture of the cloud to be constructed at each of the given times. The particular cloud dimensions exploited in this analysis, for use in the JTCG/ME Smoke Obscuration Model, are discussed in Section 3.

## 3. APPLICATION OF MEASURED DATA

The measurements of cloud characteristics presented in Appendix A were used for the following:

- a. To obtain the height and width of the WP cloud just after the weapon phase, as a function of munition fill weight. The end of the "weapon phase" is the time when the glowing orange hemisphere becomes a white cloud, which is generally about one second after burst.

- b. To calculate parameters for a function giving the height of the centroid of the WP plume as a function of time; a similar study was made of the farthest downwind portion of HC clouds, as this is the portion of the cloud where separation from the ground surface occurs. These parameters are given in Table 3.

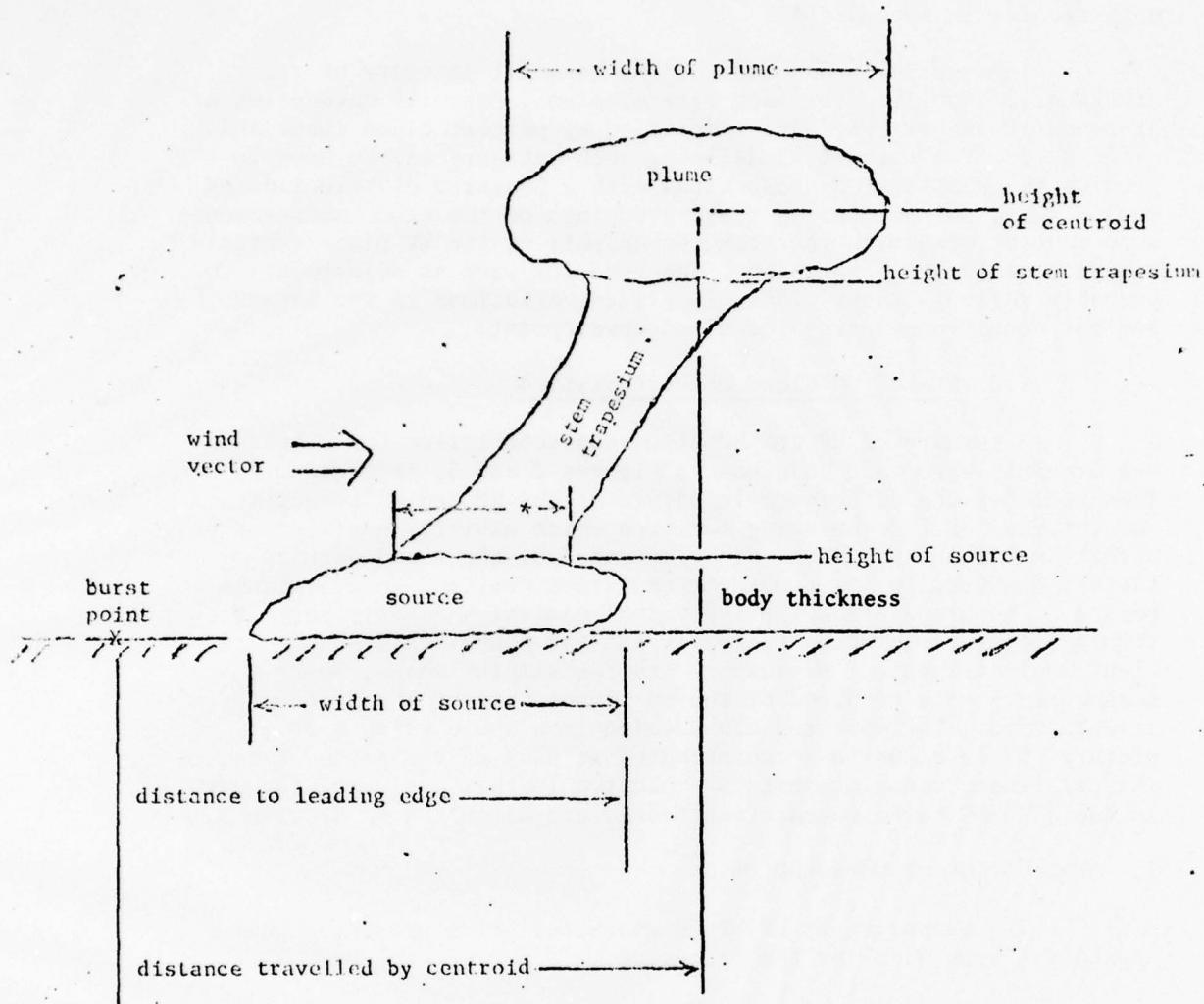


Figure 2. Summary WP Cloud Characteristics

\*base of stem trapezium.

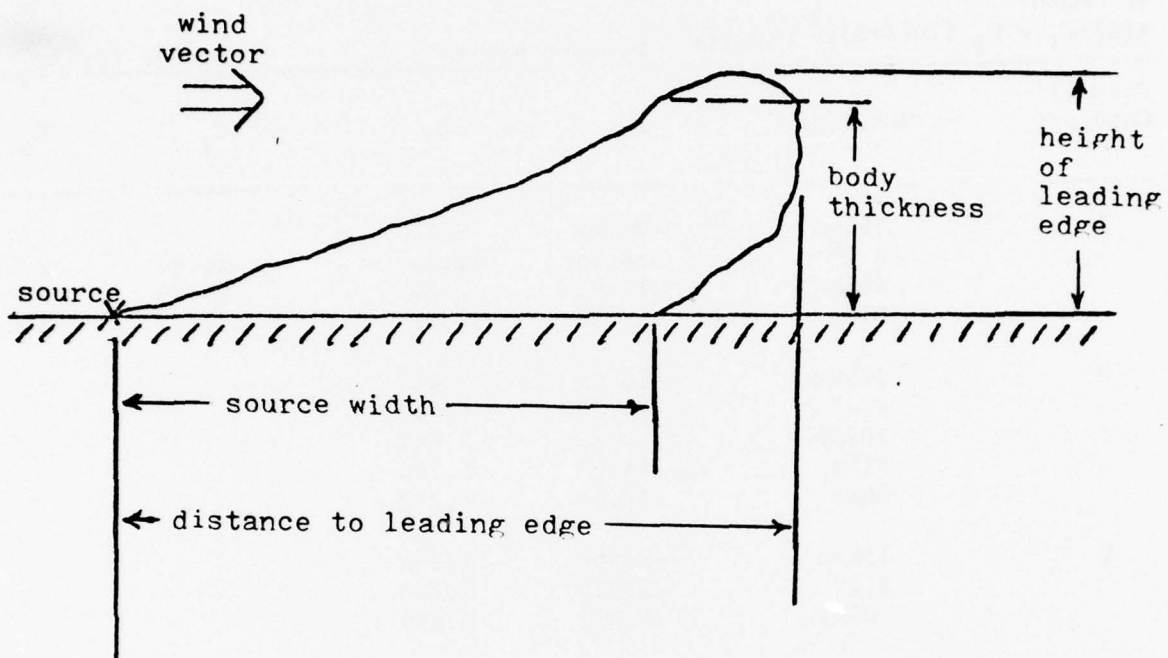


Figure 3. Summary of HC Cloud Characteristics



TABLE 3. PARAMETERS FOR CLOUD RISE FUNCTIONS

WP Smoke:  
 $z(t) = C_1 + C_2 (\ln(t+5))^2$

Pasquill Category	Munition	Dynamic Firing		Static Firing	
		$C_1$	$C_2$	$C_1$	$C_2$
A	155mm	-23.07	9.428		
	4.2"	-30.34	12.15	-31.44	12.57
	105mm	-17.91	7.27	-23.88	8.862
	81mm	-27.33	10.91	-9.674	4.097
B	155mm	-18.03	7.482		
	4.2"	-16.80	6.919		
	105mm	-9.032	3.842		
	81mm	-14.07	5.795		
	60mm	-10.48	4.272		
C	155mm	-9.968	4.369		
	4.2"	-5.922	2.720		
	105mm	-5.909	2.636		

HC Smoke:  
 $z(t) = m \cdot t + b$

Pasquill Category	Munition	Dynamic Firing		Static Firing	
		$m$	$b$	$m$	$b$
A	155mm			0.129	1.4
	105mm	0.650	1.5		
B	155mm	0.555	1.5		
	105mm	0.237	1.35		
C	155mm	0.173	1.6		

### 3.1 Source Description

The Smoke Obscuration Model represents a smoke cloud as a Gaussian distribution of agent. To initiate the growth of the cloud, a measure of the base diameter and the height of the cloud at the time of its formation are needed. These measures are referred to as the "source sigmas" of the distribution, where  $4\sigma_{xs}$  ( $=4\sigma_{ys}$ ) represent the base diameter in the windward and crosswind directions, respectively, and  $4\sigma_{zs}$  represents the height, wherein more than 99% of the cloud material is contained. The existing values, represented by the solid lines in Figure 4, are based on numerous experimental data points for mortar rounds compiled from the literature by Mr. M. C. Johnson.<sup>(1)</sup> Some of the points had been crudely measured hence the need for verification.

Measurements of the source sigmas from the JPG test are given in Figure 4 as circled dots. They were averaged for each WP munition, independent of meteorological conditions and other factors which were considered to be non-influential at such early times. The measured  $\sigma_{ys}$  values for both mortar and artillery lie fairly close to the solid  $\sigma_{ys}$  curve. However, their consistently greater value than the existing values may indicate that the curve should be adjusted upward. The measured  $\sigma_{zs}$  values for the mortar rounds lie close to the existing curve for  $\sigma_{zs}$ , but, as noted above, their consistently higher values may indicate that the existing curve for  $\sigma_{zs}$  should be adjusted upward. The test values for the  $\sigma_{zs}$  artillery rounds are so much higher than those for the mortar rounds that a separate curve may be indicated, as shown by the dashed line in Figure 4. If the  $\sigma_{zs}$  values for artillery and mortar rounds may be lumped together, as in the case of  $\sigma_{ys}$ , then the existing  $\sigma_{zs}$  curve should still be adjusted upward.

### 3.2 WP Plume Rise Models

The smoke cloud produced by the conventional, bulk-filled WP munitions generally exhibits a strong pluming effect, due to the high heat flux from the burning smoke agent. Because the plume generally contains a high percentage of the original fill weight, and because of its tactical value, its influence must be considered in certain calculations of smoke obscuration.

Two mathematical forms which predict the height of the centroid of the plume were considered for application to the JPG data: the Joules model,<sup>(3)</sup> which was developed from a consideration of basic principles of the growth of the plume (see Appendix C), and was

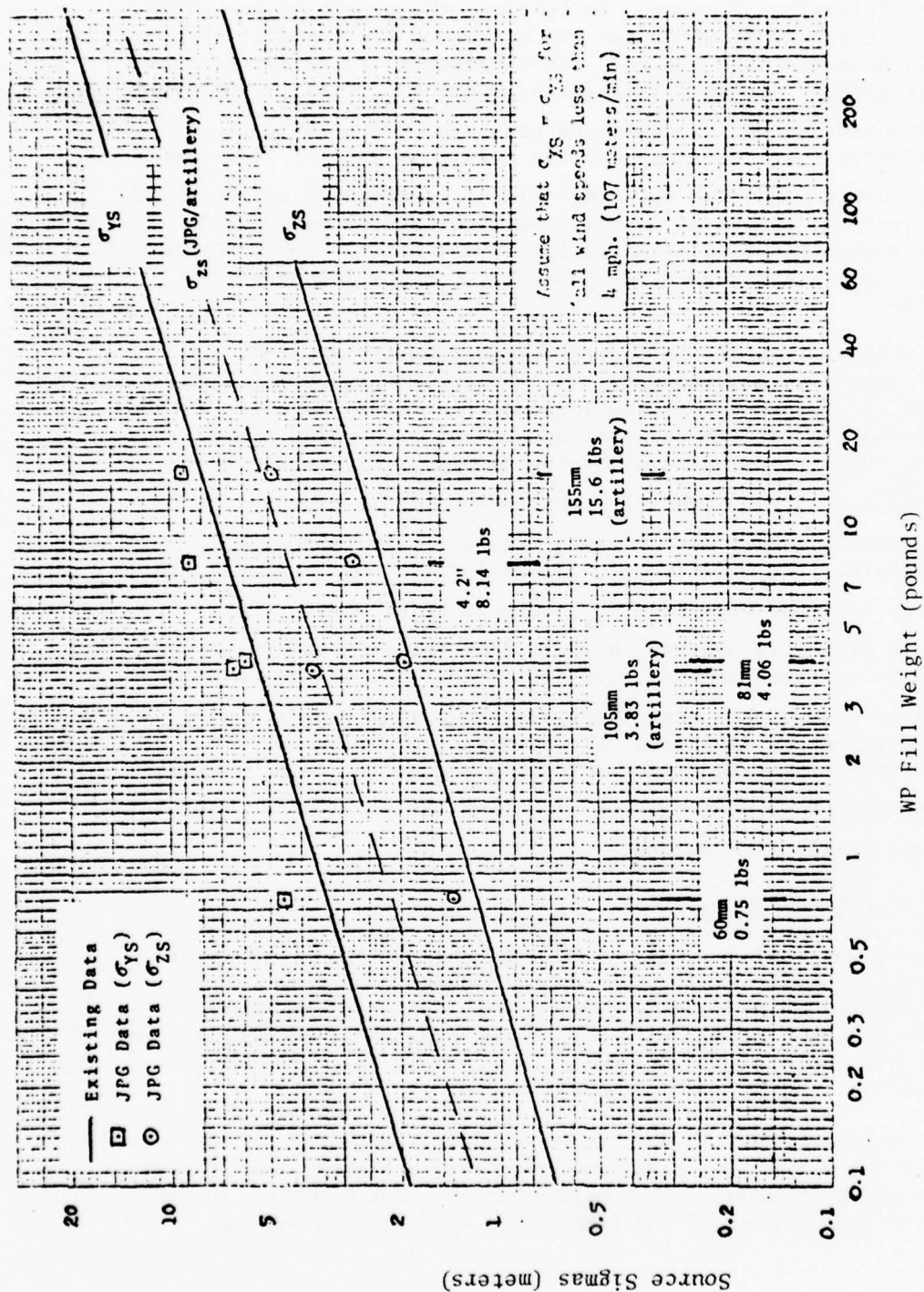


Figure 4. Source Sigmas vs WP Fill Weights

intended primarily as a research tool; and a modified logarithmic function which was an accurate and convenient curve fit of the data. Because of its explicit use of several interesting variables, an effort was made to implement the Joules model. However, for reasons of expediency, this attempt was abandoned in favor of the curve fit form.

The expression, given, below, is a function of time only, and is implicitly a function of munition, wind speed, and condition of atmospheric stability:

$$Z(t) = C_1 + C_2 (\ln(t + 5))^2, \text{ where}$$

$z$  = height of centroid (m)

$t$  = time after burst (sec.)

$C_1, C_2$  are constants determined by a least squares fit of the function to the data.

Figures 9 through 11 give the height of centroid for the 155mm WP, Pasquill categories, A, B and C, respectively, as generated by the Joules function (based on Yuma Proving Ground data) and the curve fit (based on Jefferson Proving Ground data). The "adjusted curve fit," which appears in several of the figures, is simply the curve fit to the given data points which was translated vertically to conform to the initial size of the cloud ( $\sigma_z$ ) at  $t=0$ . Considering the numerous sources of discrepancy, the comparison is quite reasonable. Graphs of the height of rise data and their fitted functions for other WP munitions are given in Figures 12 through 20. Table 3 contains the values of  $C_1$  and  $C_2$  for all of the curve fits.

### 3.3 HC Cloud Rise Model

Without a separate, explicit cloud rise function, the Smoke Obscuration Model permits the centroid of a cloud to rise only as a result of cloud expansion. Based on observations of HC clouds, this assumption seemed to be questionable when applied to the leading portion of an HC cloud. For this reason data describing the rate of rise of the centroid of the leading portion of HC clouds were extracted from the JPG test results. A linear function was successfully applied to curve fit these cases. Their graphs and curve fitted parameters are given in Figures 21 through 24 and in Table 1, respectively.

### 3.4 Static Firings

Cloud characteristics were also measured for several static firings. A comparison with the rise functions for the dynamic shots



would indicate the influence of the motion of the projectile, entrenchment of smoke agent particles in the earth, etc. These graphs and curve fitted parameters are given in Figures 25 through 29 and in Table 1, respectively.

#### 4. CONCLUSIONS

a. The JPG test data indicate that the source sigmas currently used in the Smoke Obscuration Model may be about 45 percent low for artillery munitions.

b. The test data indicate that separate functions for the initial vertical component of cloud growth for artillery and mortar munitions may be needed.

c. The test data and curve fit function for the rise of the centroid of the 155mm WP plume closely approximate for predictions by the more sophisticated Joules rise function.

d. The height of rise of the centroid of the downwind portion of HC clouds may be represented by a simple linear function of time.

It is recommended that each of these aspects of data and extraction and analysis be separated with other smoke tests, and the results amalgamated with those presented herein.

#### REFERENCES

1. Ford, B., Support Test of Artillery and Mortar Smoke Munitions, Final Report; USA Jefferson Proving Ground, Test Report No. 75-1789, September 1975. UNCLASSIFIED.
2. Johnson, M.C., and Forney, P. D., The Effectiveness of Obscuring Smokes, (Unpublished). UNCLASSIFIED
3. Joules, R. G., Vertical Rise of a Heated Plume; ARMCOM Methodology Division Memorandum for Record, 28 April 1975.
4. Progress Report on the Development of a BCW Forecast System; Booz-Allen Applied Research Inc., Report No. 141-2-16-R7, October 1963. UNCLASSIFIED.

Next page is blank

APPENDIX A. CLOUD DATA SHEETS

Next page is blank

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 60mm WP  
Shot Number A-1 S Looking E

Date Aug. 19  
Time of Firing 1557

Wind Speed (kts) 3-4  
% Cloud Cover 90  
Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction (°TN) 315

Frame No.	Time (Sec)	Source		Stem		Plume Centroid		Width of Plume (m)
		Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
1	0	12.9	4.57					
3	.125	15.1	4.57					
8	.333	15.1	5.33					
11	.458	16.2	6.1					
18	.75	20.5	6.1					
25	1.04	23.7	6.86					
33	1.38	24.8	8.38					
48	2.00	30.2	8.38					
57	2.38	32.3	24.4					
64	2.67	32.3	25.9					
76	3.17	32.3	27.4					
88	3.67		13.7	30.2	10.7			
118	4.92		10.7	32.3	12.2		11.4	18.1
141	5.88		13.0	32.3	10.7		12.2	21.6
165	6.88		15.2	32.3	10.7		12.2	21.6
199	8.29		16.8	28.0	9.14		14.5	25.9
240	10.		15.2	15.1	10.7		19.1	28.0
288	12.		18.3	19.4	9.14		21.3	30.2



JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 60mm WP  
Shot Number A-1 (Cont)

Date Aug. 19  
Time of firing 1557

Wind Speed (kts) 3-4  
% Cloud Cover 90  
Particle Dispersion Width (m)                     

Wind Direction ( $^{\circ}$ TN) 315

[illegible]

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 155mm WP  
Shot Number A-5 S looking E

Date Aug. 19  
Time of Firing 1640

Wind Speed (kts) 3-4

Wind Direction (°TN) 340

% Cloud Cover 90

Particle Dispersion Width (m) 182

[illegible]

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 155mm WP  
Shot Number E-5 S looking E

Date Aug. 20  
Time of Firing 1650

Wind Speed (kts) 3-3.5  
% Cloud Cover 75  
Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction (°TN) 161[illegible]

\* still burning

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 4.2" WP  
Shot Number B-3 S looking N

Date Aug. 20  
Time of Firing 1320

Wind Speed (kts) 1-2  
% Cloud Cover 60  
Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction ( $^{\circ}$ TN) 25

[illegible]



## CLOUD CHARACTERISTICS

32

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 4.2" WP  
Shot Number D-3 S looking E

Date Aug. 20  
Time of Firing 1618

Wind Speed (kts) 3  
% Cloud Cover 75  
Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction (°TH) 20

Frame No.	Time (Sec)	Source		Stem		Plume Centroid		Width of Plume (m)
		Width (m)	Thickness (m)	Trapezium Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
1	0	15.1	5.08					
4	.167	24.9	5.59					
15	.625	34.6	6.1					
27 +	1.13							
76	3.17			19.5	10.8		9.14	
190	7.92	29.2	22.4	46.5	10.8		20.3	
325	13.5	35.7	30.5	50.8	25.9		35.6	
478	19.9	49.7	40.6	51.9	35.7		43.7	
623	26.0	54.1	45.7	45.4	43.1		54.9	
841	35.0	73.0	58.4	43.2	54.1		67.3	
1058	44.1	90.6	68.5	46.5	64.9		81.3	
1318	54.9	118.9	76.2	45.4	83.8		109.	

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 4.2" WP  
Shot Number E-3 S looking E

Date Aug. 20  
Time of Firing 1635

Wind Speed (kts) 1.2  
% Cloud Cover 75  
Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction (°TN) 161

[illegible]

\* still burning  
+ end of weapon phase

# JEFFERSON PROVING GROUND SMOKE TEST CLOUD CHARACTERISTICS

Munition 4.2" WP  
Shot Number F-3 S looking E

Date Aug. 20  
Time of Firing 1815

Wind Speed (kts) 2.5  
% Cloud Cover 75  
Particle Dispersion Width (m)                     

Wind Direction ( $^{\circ}$ TN) 160

[illegible]

\* still burning

+ end of weapon phase



JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 105mm WP  
Shot Number C-4 S Looking E

Date Aug. 20  
Time of Firing 1445

Wind Speed (kts) 4-6.5  
% Cloud Cover 75  
Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction (°TN) 161[illegible]

# JEFFERSON PROVING GROUND SMOKE TEST CLOUD CHARACTERISTICS

Munition 81mm WP  
Shot Number C-2 S Looking N

Date Aug. 20  
Time of Firing 1345

Wind Speed (kts) 1-2.3  
 % Cloud Cover 75  
 Particle Dispersion Width (m).

Wind Direction ( $^{\circ}$ TN) 20

[illegible]

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 81mm WP  
Shot Number F-2 S looking E

Date Aug. 20  
Time of Firing 1822

Wind Speed (kts) 2.4  
% Cloud Cover 75

Wind Direction ( $^{\circ}$ TN) 165

Particle Dispersion Width (m) \_\_\_\_\_

[illegible]

+ end of weapon

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 60mm WP  
Shot Number C-1 S looking N

Date Aug. 20  
Time of Firing 1343

Wind Speed (kts) 1-2.2  
 % Cloud Cover 75  
 Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction (°TN) 295[illegible]

+ end of weapon phase



# JEFFERSON PROVING GROUND SMOKE TEST CLOUD CHARACTERISTICS

Munition 60mm WP  
Shot Number F-1 S looking E

Date Aug. 20  
Time of Firing 1822

Wind Speed (kts) 2.2 - 2.6

Wind Direction (°TN) 200

% Cloud Cover 75

Particle Dispersion Width (m) \_\_\_\_\_

[illegible]

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 155mm HC  
Shot Number A-7 S looking N

Date Aug. 20  
Time of Firing 1140

Wind Speed (kts) 3-4

Wind Direction (°TH) 157

% Cloud Cover 30

Burn Time (sec) \_\_\_\_\_

Cannister Dispersion (m) \_\_\_\_\_

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	1.08	19.9	6.1		
2	1.08	15.9	4.6		
3	1.08	9.93	3.05		
1, 2	2.0	35.9	9.9		
3	2.0	12.0	9.6		
3	3.54			51.7	12.2
3	3.54			13.9	6.1
3	6.04				
	8.46*				
	17.0	215		243	24.4
	29.5	319		350	36.6
	37.8	370		418	51.4
	46.2	398		458	61.0
	54.5	408		513	68.6
	63.1	438		533	91.4
	71.3	403		488	113
	84.8	433		508	133

\* merger of individual clouds

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 155mm HC  
Shot Number B-7 S looking N

Date Aug. 20  
Time of Firing 1145

Wind Speed (kts) 2-3  
% Cloud Cover 30  
Cannister Dispersion (m)                     

Wind Direction ( $^{\circ}$ TN)                       
Burn Time (sec) 202

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	5.63	17.6		22.0	8.13
2	5.63	17.6		13.2	6.10
3	5.63	17.6		11.0	8.13
4	5.63	7.70		11.0	5.08
1	13.4	35.2	9.14	39.6	
2	13.4	17.6	19.3	26.4	
3	13.4	39.6	16.3	48.4	
1	21.6	41.8		61.6	26.4
2	21.6	41.8		57.2	24.4
1	29.9	48.4	26.4	70.4	
2	29.9	61.6	30.5	72.6	
	38.5*	108		126	36.6
	59.1	137		165	55.9
	66.7	159		176	66.0

\* merger of individual clouds

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 155mm HC  
Shot Number E-7 S looking E

Date Aug. 20  
Time of Firing 1746

Wind Speed (kts) 2.5-3  
% Cloud Cover 75  
Cannister Dispersion (m)                     

Wind Direction (<sup>0</sup>TN) 71  
Burn Time (sec)                     

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	.042	23.3	5.54	33.2	
2	.042	16.6	3.33	33.2	
3	.042	9.98		9.98	
1	1.13	33.2	5.54	43.2	
2	1.13	19.3	3.33	39.8	
3	1.13	13.3	4.43	13.3	
1, 2	4.08	73.1		73.1	3.33
3	4.08	21.6		21.6	6.64
	10.6*	120		133	9.97
	19.4	154		179	13.3
	29.4	203		245	13.3
	41.5	266		332	16.6
	53.8	349		419	22.2
	66.6	415		498	27.7

\* merger of individual clouds



JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 155mm HC  
Shot Number F-7 S looking E

Date Aug. 20  
Time of Firing 1754

Wind Speed (kts) 2.5-3  
% Cloud Cover 75  
Cannister Dispersion (m) \_\_\_\_\_

Wind Direction ( $^{\circ}$ TN) 65  
Burn Time (sec)           

[illegible]

## JEFFERSON PROVING GROUND SMOKE TEST

## CLOUD CHARACTERISTICS

Munition 105mm HC  
Shot Number B-6 S looking N

Date Aug. 20  
Time of Firing 1152

Wind Speed (kts) 0-1  
% Cloud Cover 30  
Cannister Dispersion (m) 24.4

Wind Direction ( $^{\circ}$ TN) 157  
Burn Time (sec) 91-100

[illegible]

\* merger of individual clouds

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 105mm HC  
Shot Number C-6 S looking E

Date Aug. 20  
Time of Firing 1507

Wind Speed (kts) 4-6  
% Cloud Cover 75  
Cannister Dispersion (m) 104

Wind Direction (°TN) 71  
Burn Time (sec) \_\_\_\_\_

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	.83	18.2			2.4
2	.83	7.31			3.7
3	.83	11.0			3.0
1	5.29	47.3		47.3	2.4
2	5.29	18.3		25.5	8.5
3	5.29	18.3		25.5	6.1
1	12.8	110.		110.	6.1
2	12.8	47.3		62.0	14.6
3	12.8	58.4		76.7	8.5
	21.1*			283.	9.1
	29.6	288.		329.	14.6
	38.3	332		374.	17.1
	50.9	402		475	28.0
	63.8	475		534	24.4
	83.9	612		685	29.3
	84.6	717		795	45.1

\* merger of individual clouds

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 155mm MP  
Shot Number G-5 S looking N

Date Aug. 21  
Time of firing 1123

Wind Speed (kts) 6-8

Wind Direction ( $^{\circ}$ TH) 210% Cloud Cover 0

Particle Dispersion Width (m) \_\_\_\_\_

[illegible]

+ end of weapon phase



JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 155mm WP  
Shot Number H-5 S looking N

Date Aug. 21  
Time of Firing 1240

Wind Speed (kts) 3-6

Wind Direction ( $^{\circ}$ TN) 245

% Cloud Cover 50

Particle Dispersion Width (m) \_\_\_\_\_

Frame No.	Time (Sec)	Source		Stem		Plume Centroid		Width of Plume (m)
		Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
1	0	18.5	5.57					
2	.083	24.6	8.36					
5	.208	24.6	9.75					
16	.67 +	35.4	20.9					
24	1.0	49.2	23.7					
42	1.75	72.3	30.7			7.70		
57	2.38	99.9	36.2			15.1		
75	3.13	99.9	22.3	99.9	23.7	18.5	33.4	27.7
99	4.13	138	26.5	26.1	33.4	24.6	46.0	33.8
146	6.08	154	39.0	23.1	44.6	38.4	57.1	46.1
198	8.25	158	44.6	33.8	51.6	50.7	65.5	61.5
243	10.1	165	55.7	30.7	58.5	66.1	76.6	69.2
292	12.2	174	62.7	38.4	65.5	80.0	80.8	83.0
388	16.2	177	62.7	53.8	69.7	115	90.6	111
446	18.6	191	61.3	76.9	65.5	131	90.6	115

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 105mm HC  
Shot Number D-6 S looking E

Date Aug. 20  
Time of Firing 1528

Wind Speed (kts) 3-5  
% Cloud Cover 75  
Cannister Dispersion (m)                     

Wind Direction (<sup>0</sup>TN) 71  
Burn Time (sec)                     

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	1.04	11.0	2.44		
2	1.04	11.7	3.90		
3	1.04	11.0	3.66		
1	3.21	29.2	3.66		
2	3.21	11.0	4.88		
3	3.21	14.6			
1	8.75	51.1		58.5	4.27
2	8.75	21.9		32.9	10.4
3	8.75	40.2		47.5	6.71
1	14.9	87.7		102.	6.71
2	14.9	47.5		65.8	15.9
3	14.9	58.5		76.7	9.75
	20.5*	256		270	11.0
	30.9	292		329	15.9
	42.8	358		402	19.5
	59.2	449		493	20.7
	76.4	544		621	34.1
	88.3	636		712	36.6
	99.0	712		794	48.8

\* merger of individual clouds

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 155mm WP  
Shot Number I-5 S looking N

Date Aug. 21  
Time of Firing 1416

Wind Speed (kts) 4-6  
% Cloud Cover 50  
Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction (°TN) 250

[illegible]

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 155mm WP  
Shot Number J-5 S Looking N

Date Aug. 21  
Time of Firing 1505

Wind Speed (kts) 4-6  
% Cloud Cover 50  
Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction (°TN) 260

Frame No.	Time (Sec)	Source		Stem		Plume Centroid		Width of Plume (m)
		Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
1	0	16.5	8.13					
3	.125	28.9	12.2					
7	.29	35.1	18.3					
15	.63	41.3	22.4					
19	.79	41.3	24.4					
24	1.0	47.5	28.5					
48	2.0	76.4	32.5					
96	4.0	99.0	20.3			31.0	38.6	35.1
148	6.17	134	32.5			51.6	52.8	47.5
216	9.0	161	46.7			86.7	67.1	74.3
241	10.0	161	50.8			94.9	71.1	74.3
360	15.0	206	52.8			144	81.3	108
480	20.0	268	61.0			1.98	87.4	124
562	23.4	310	67.1			239	87.4	129
724	30.2	361	71.1			315	102	134



JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 4.2" WP  
Shot Number G-3 S looking N

Date Aug. 21  
Time of Firing 1052

Wind Speed (kts) 6-8  
% Cloud Cover 0  
Particle Dispersion Width (m)                     

Wind Direction ( $^{\circ}$ TN) 225

Frame No.	Time (Sec)	Source		Stem		Plume Centroid		Width of Plume (m)
		Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
	0	41.7	9.14					
	.292	71.8	12.2					
	.708	106 +	18.3					
	3.0	167	26.4					
	5.0	175	42.7					
	10.0	194	16.3			69.0	36.6	83.3
	15.0	204	20.3			101	50.8	77.6
	20.0	207	20.3			132	54.9	94.9
	25.0	218	24.4	54.6	86.2	161	81.3	115
	30.0	194	24.4	71.8	91.9	180	89.4	126
	35.1	216	24.4	69.0	86.2	194	89.4	138
	40.0	223	30.5	71.8	94.9	208	93.5	158
	45.0	237	52.8			233	91.4	144
	50.1	266	61.0			252	96.5	129
	55.0	287	52.8			266	91.4	138

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 4.2" WP  
Shot Number H-3 S Looking N

Date Aug. 21  
Time of Firing 1303

Wind Speed (kts) 4-8  
% Cloud Cover 50  
Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction (°TN) 245

Frame No.	Time (Sec)	Source		Stem		Plume Centroid		Width of Plume (m)
		Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
1	0	15.7	6.1					
14 <sup>+</sup>	.58	33.6	10.2					
24	1.0	49.3	10.2					
48	2.0	58.3	16.3					
72	3.0	67.3	20.3					
96	4.0	80.7	24.4					
120	5.0	83.0	23.5					
170	7.08	89.7	36.6					
192	8.0	91.9	40.6					
240	10.0	89.7	46.7					
360	15.0	117	12.2			98.6	34.6	80.7
480	20.0	168	16.3			135	36.6	101
600	25.0	202	20.3			168	46.7	123
720	30.0	235	26.4			202	50.8	135
770	32.1	247	24.4			213	54.9	140
837	34.1	247	28.5			247	56.9	139

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 4.2" WP  
Shot Number J-3 S looking N

Date Aug. 21  
Time of firing 1533

Wind Speed (kts) 3-6  
% Cloud Cover 50  
Particle Dispersion Width (m)                     

Wind Direction (°TH) 260

Frame No.	Time (Sec)	Source		Stem		Plume Centroid		Width of Plume (m)
		Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
	417	51.6	12.2					
	833	51.6 <sup>+</sup>	14.2					
	1.0	66.0	16.3					
	2.0	86.6	18.3					
	4.0	103.2	14.2			14.4	26.4	37.2
	5.0	109.4	18.3			20.6	30.5	45.4
	8.0	103.2	24.4			28.8	46.7	57.8
	10.0	113.5	34.5			36.2	56.9	61.9
	15.0	121.8	44.7			53.6	79.3	78.4
	20.0	118.6	54.9			72.2	89.4	92.3
	25.0	123.8	65.0			87.7	105.7	103
	30.0	134.2	67.1			103	111.8	124
	35.0	146.5	67.1			107	130.1	128
	40.0	156.8	71.1			129	137.2	124
	45.0	158.9	86.4			150	146.3	144
	50.0	170.2	91.4			173	150.4	144
	62.5	185.7	93.5			229	162.6	136

+ end of weapon phase

## JEFFERSON PROVING GROUND SMOKE TEST

## CLOUD CHARACTERISTICS

Munition 105mm WP  
Shot Number H-4 S looking N

Date Aug. 21  
Time of Firing 1255

Wind Speed (kts) 4-8  
Cloud Cover 50  
Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction ( $^{\circ}$ TN) 245

[illegible]



JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 105mm WP  
Shot Number I-4

Date Aug. 21  
Time of Firing 1410

Wind Speed (kts) 4-6  
% Cloud Cover \_\_\_\_\_  
Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction (°TH) 250

Frame No.	Time (Sec)	Source		Stem		Plume Centroid		Width of Plume (m)
		Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
1	0	13.0	4.57					
8	.33	32.4	12.2					
24	1.0	43.8	15.2					
49	2.04	48.7	18.3					
96	4.0	48.7	7.62				13.7	32.4
169	7.04	64.9	10.7			42.2	22.9	35.7
242	10.1	69.7	15.2			58.4	25.9	40.5
363	15.1	101	15.2			86.0	35.1	48.7
480	20.0	115	12.2	24.3	24.3	109	35.1	56.8
600	25.0	131	16.8	27.6	24.3	136	39.6	56.8
720	30.0	148	15.2	24.3	25.9	161	41.2	55.1
840	35.0	164		32.4	32.4	185	45.7	58.4
1,011	42.1	178		32.4	40.5	211	53.3	68.1



JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 105mm WP  
Shot Number J-4 S looking N

Date Aug. 21  
Time of Firing 1507

Wind Speed (kts) 4-6  
% Cloud Cover 50  
Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction ( $^{\circ}$ TH) 260

Frame No.	Time (Sec)	Source		Stem		Plume Centroid		Width of Plume (m)
		Width (m)	Thickness (m)	Trapezium Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
	0	4.12	3.05					
	.208	24.8	12.2					
	.542 <sup>+</sup>	26.8	18.3					
	.75	33.0	20.3					
	1.0	35.1	22.4					
	2.04	47.5	26.4					
	4.0	66.0	36.6					
	6.0	66.0	20.3			47.7	30.5	45.4
	8.0	88.7	20.3			64.0	32.5	47.4
	10.0	92.9	24.4			78.4	38.6	45.4
	15.0	126	10.2	26.8	31.0	120	50.8	45.4
	20.0	150	10.2	37.1	41.3	165	67.1	57.8
	25.0	186	12.2	33.0	49.5	206	69.1	68.1
	30.0	212	14.2	37.1	55.7	243	77.2	72.2
	35.0	253	20.3	47.5	51.6	277	77.2	86.6
	40.0	294	12.2	61.9	51.6	325	75.2	103

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 81mm WP  
Shot Number G-2 S looking N

Date Aug. 21  
Time of Firing 1047

Wind Speed (kts) 6-8  
% Cloud Cover 0  
Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction (°TN) 210

Frame No.	Time (Sec)	Source		Stem		Plume Centroid		Width of Plume (m)
		Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
	0	24.4	6.10					
	.208	36.6	6.10					
	1.0 +	56.8	10.2					
	2.0	81.2	13.2					
	3.08	93.4	19.3					
	3.83	89.4	20.3					
	5.0	142	26.4					
	10.0	159	10.2			16.3	20.3	40.6
	15.0	142	10.2			24.4	30.5	102
	20.0	146	10.2			40.6	34.5	122
	25.0	146	34.5			61.0	56.9	134
	30.0	173	38.6			81.2	58.9	114
	35.0	195	40.6			102	65.0	122
	40.0	203	52.8			114	71.1	114
	45.0	183	54.9			138	71.1	122
	50.0	175	50.8			150	73.2	138

\* Plume was situated directly atop source, hence no stem.

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 81mm WP  
Shot Number H-2 S looking N

Date Aug. 21  
Time of Firing 1309

Wind Speed (kts) 4-8  
% Cloud Cover 50  
Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction (°TN) 245

Frame No.	Time (Sec)	Source		Stem		Plume Centroid		Width of Plume (m)
		Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
1	0	6.7	3.8					
12	0.5 <sup>+</sup>	26.9	6.9					
24	1.0	31.9	7.62					
48	2.0	33.6	13.7					
68	2.83	28.6	4.57			10.1	9.14	16.8
77	3.21	28.6	4.57			11.8	10.7	16.8
126	5.25	28.6	6.09			21.9	19.8	20.1
168	7.0	33.6	7.62			28.6	22.9	23.5
216	9.0	40.4	3.80	16.8	16.8	37.0	33.5	25.2
270	11.3	47.1	7.62	25.2	23.5	43.7	44.2	30.3
360	15.0	55.5	15.2	18.5	42.0	63.9	57.9	35.3
480	20.0	70.6	10.7	20.2	62.2	89.1	78.2	43.7
600	25.0	80.1	15.2	21.8	95.9	118	96.0	53.8
720	30.0	103	15.2	25.2	92.5	136	111	58.9

+ end of weapon phase

## CLOUD CHARACTERISTICS

Shot Number I-2 S looking N

Time of Firing 1315

Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction ( $^{\circ}$ TN) 245

[illegible]

\* Source Width could not be measured because its separation from the nearly-simultaneous case I-1 was not clear.

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 60mm WP  
Shot Number H-1 S Looking N

Date Aug. 21  
Time of Firing 1309

Wind Speed (kts) 4-8  
 % Cloud Cover 50  
 Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction ( $^{\circ}$ N) 245

[illegible]



# JEFFERSON PROVING GROUND SMOKE TEST CLOUD CHARACTERISTICS

Munition 60mm WP  
Shot Number 1-1

Date Aug. 21  
Time of Firing 1315

Wind Speed (kts) 4-7

Wind Direction (°TN) 245

% Cloud Cover 50  
Particle Dispersion Width (m)                     

[illegible]

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 155mm HC  
Shot Number I 7 S looking N

Date Aug 21  
Time of Firing 1428

Wind Speed (kts) 5-8  
% Cloud Cover 50  
Cannister Dispersion (m)                     

Wind Direction ( $^{\circ}$ TN) 328  
Burn Time (sec)                     

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	3.0	35.9	3.05		
2	3.0	11.9	1.52		
3, 4	3.0	47.8	4.57		
1	7.67	75.7	6.09		
2	7.67	47.8	6.09		
3	7.67	83.6	4.57		
1, 2	15.0	159.	15.2	159	
3, 4	15.0	159.	9.14	159	
1, 2	20.0	187	25.9	187	
3, 4	20.0	199	10.7	199	
1, 2	25.0	239	33.5	239	
3, 4	25.0	243	12.2	243	
1, 2	30.0	287	45.7	189	
3, 4	30.0	319	16.8	299	
1, 2	35.0	339	53.3	207	
3, 4	35.0	358	25.9	269	
	40.0	538	61.0	508	
	45.0	569	61.0	526	

## JEFFERSON PROVING GROUND SMOKE TEST

## CLOUD CHARACTERISTICS

Munition 155mm HC  
Shot Number I-7 (Cont)

Date Aug. 21  
Time of Firing 1428

Wind Speed (kts) 5-8

Wind Direction ( $^{\circ}$ TN) \_\_\_\_\_% Cloud Cover 50

Burn Time (sec) \_\_\_\_\_

Cannister Dispersion (m) \_\_\_\_\_

[illegible]

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 105mm HC  
Shot Number I-6 S looking N

Date Aug. 21  
Time of Firing 1422

Wind Speed (kts) 5-8  
% Cloud Cover 50  
Cannister Dispersion (m)                     

Wind Direction ( $^{\circ}$ TN) 315  
Burn Time (sec)                     

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	1.75	17.2	2.03		
2	1.75	23.0	4.06		
3	1.75	8.61	8.13		
1	4.0	23.0	4.06	23.0	
2	4.0	43.1	8.31	43.1	
3	4.0	28.7	10.2	28.7	
1	6.0	34.5	6.09	34.5	
2	6.0	54.6	8.13	54.6	
3	6.0	46.0	16.3	46.0	
1	10.0	48.9	12.2	48.9	
2	10.0	71.8	12.2	71.8	
3	10.0	71.8	16.3	51.7	
1	15.0	94.8	16.3	94.8	
2	15.0	112	12.2	112.	
3	15.0	115	20.3	54.6	
2	20.0	109	10.2	109.	
3	20.0	172	10.2	97.7	
	25.0*	330	36.6	244	

\* Merger of individual clouds.

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 105mm HC  
Shot Number I-6 (Cont)

Date Aug. 21  
Time of Firing 1422

Wind Speed (kts) 5-8  
% Cloud Cover 50  
Canister Dispersion (m) \_\_\_\_\_

Wind Direction (<sup>0</sup>TN) 315  
Burn Time (sec) \_\_\_\_\_

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
	30.0	330.	40.6	273	
	35.0	345.	38.6	316	
1, 2	40.0	150.9	16.3	150.9	
3	40.0	215.5	30.5	172.4	
1, 2	45.0	172.4	20.3	172.4	
3	45.0	229.9	30.5	172.4	
1, 2	50.0	194	24.4	194	
3	50.0	229.9	28.5	201.2	
1, 2	55.0	115.7	18.3	115.7	
3	55.0	184.1	32.5	157.8	
1, 2	60.0	121.0	20.3	73.6	
3	60.0	178.8	40.6	168.3	
1, 2	65.0	126.2	20.3	126.2	
3	65.0	231.4	44.7	189.3	
1, 2	70.0	136.7	26.4	110.4	
3	70.0	226.2	44.7	189.3	
1, 2	75.0	131.5	26.3	131.5	
3	75.0	226.2	30.5	184.1	



JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 105mm HC  
Shot Number I-6 (Cont)

Date Aug 21  
Time of Firing 1422

Wind Speed (kts) 5-8  
% Cloud Cover 50  
Cannister Dispersion (ft) \_\_\_\_\_

Wind Direction ( $^{\circ}$ TN) 315  
Burn Time (sec)           

[illegible]

\* Merger of individual clouds.

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 105mm WP  
Shot Number Static

Date Aug. 21  
Time of Firing 1704

Wind Speed (kts) 2-4  
% Cloud Cover 50  
Particle Dispersion Width (m) 61.0

Wind Direction (°TN) 293

Frame No.	Time (Sec)	Source		Stem		Plume Centroid		Width of Plume (m)
		Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
1	0			13.0	6.1			
4	.17			24.0	11.0			
8	.33			27.2	10.5			
22	.92			29.5	15.5			
38	1.58	29.4	9.97	34.3	21.1		18.8	
68	2.83	37.8	24.4	33.1	20.0		24.4	
100	4.17	36.6	37.7	31.9	16.6		33.3	
128	5.33	44.9	45.4	29.5	15.0		41.0	
165	6.88	52.0	54.3	28.4	15.5		49.7	
327	13.6	66.5	72.0	33.1	25.5		62.4	
479	20.0	70.9	74.8	38.4	30.5		66.5	

\* True plume not formed; "Centroid Height" refers to the upper structure of the cloud.

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 81mm WP  
Shot Number Static S looking N

Date Aug. 21  
Time of Firing 1732

Wind Speed (kts) 2-3  
 Cloud Cover 50  
 Particle Dispersion Width (m) 15.9-62.5

Wind Direction (°TN) 293[illegible]

\* Cloud rose to rapidly to show a well-defined plume and a separate source.

+ end of weapon phase

JEFFERSON PROVING GROUND SMOKE TEST  
CLOUD CHARACTERISTICS

Munition 60mm WP  
Shot Number Static

Date Aug. 21  
Time of Firing 1732

Wind Speed (kts) 2-3  
% Cloud Cover 50  
Particle Dispersion Width (m) \_\_\_\_\_

Wind Direction (°TN) 293

Frame No.	Time (Sec)	Source		Stem		Plume Centroid		Width of Plume (m)
		Width (m)	Thickness (m)	Base (m)	Height (m)	Distance Travelled (m)	Height (m)	
							*	
1	0			19.49	5.49			
3	.125			15.6	7.32			
11	.46			16.9	8.53			
80	3.33			21.4	9.75			
153	6.38	39.0	26.8	31.2	34.1		32.9	
357	14.9	59.8	42.7	28.6	30.5		48.8	
454	18.9	70.2	43.9	38.9	32.9		53.6	
648	27.0	71.5	53.6	38.9	40.2		51.8	
762	31.8	74.1	57.3	58.5	45.1		61.0	
828	34.5	81.9	61.0	62.4	34.1		67.1	
924	38.5							

\* True plume not formed: "Centroid Height" refers to the upper structure of the cloud.

JEFFERSON PROVING GROUND SHOT TEST  
CLOUD CHARACTERISTICS

Munition 155mm HC  
Shot Number Static S looking N

Date Aug. 21  
Time of Firing 1617

Wind Speed (kts) 2.5-5  
% Cloud Cover 70.7  
Cannister Dispersion(m)

Wind Direction ( $^{\circ}$ N) 248  
Burn Time (sec)

Canister	Time (sec)	Source Width (m)	Body Thickness (m)	Distance To Leading Edge (m)	Height of Leading Edge (m)
1	1.54	11.7	2.6		
2	1.54	3.9	3.9		
3	1.54	5.2	3.9		
1	3.21	6.5	3.3		
2	3.21	8.4	3.3		
3	3.21	11.7	4.6		
1	5.46	7.8	3.9		
2	5.46	13.0	5.2		
3	5.46	22.1	5.2		
1	8.63	7.8	4.6		
2	8.63	16.9		20.1	9.1
3	8.63	26.0		28.6	7.1
2	17.0	32.5		42.8	14.3
3	17.0	29.8		40.3	12.4
	25.4*	78.0		103.9	13.0
	34.2*	90.9		126.8	14.9
	44.9*	97.4		154.6	16.2
	55.5*	179		179.1	18.2
	72.4*	173.7		182.3	19.5

\*merger of individual clouds



APPENDIX B. GRAPHS

Next page is blank

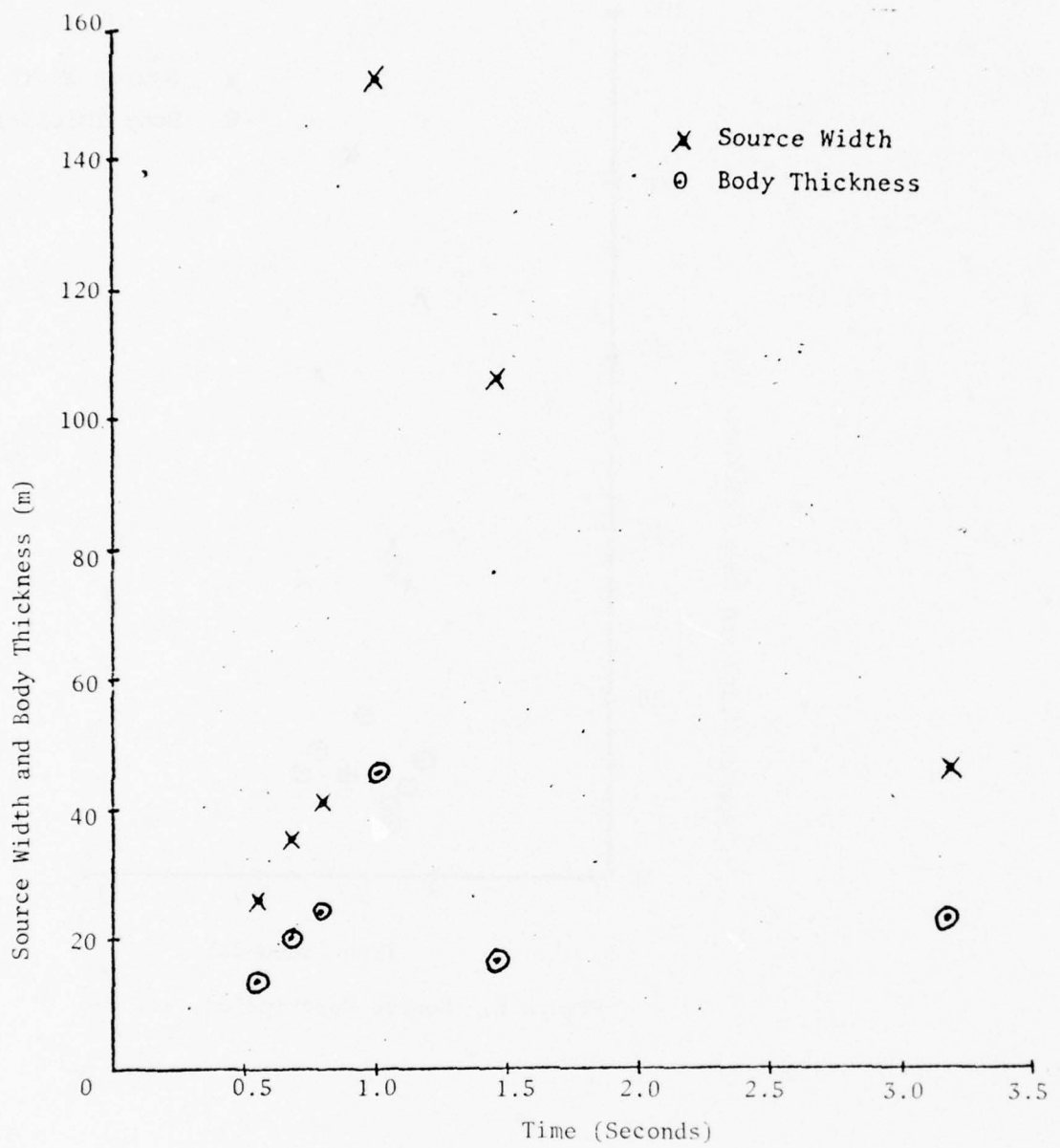


Figure 5. Source Description, 155mm WP

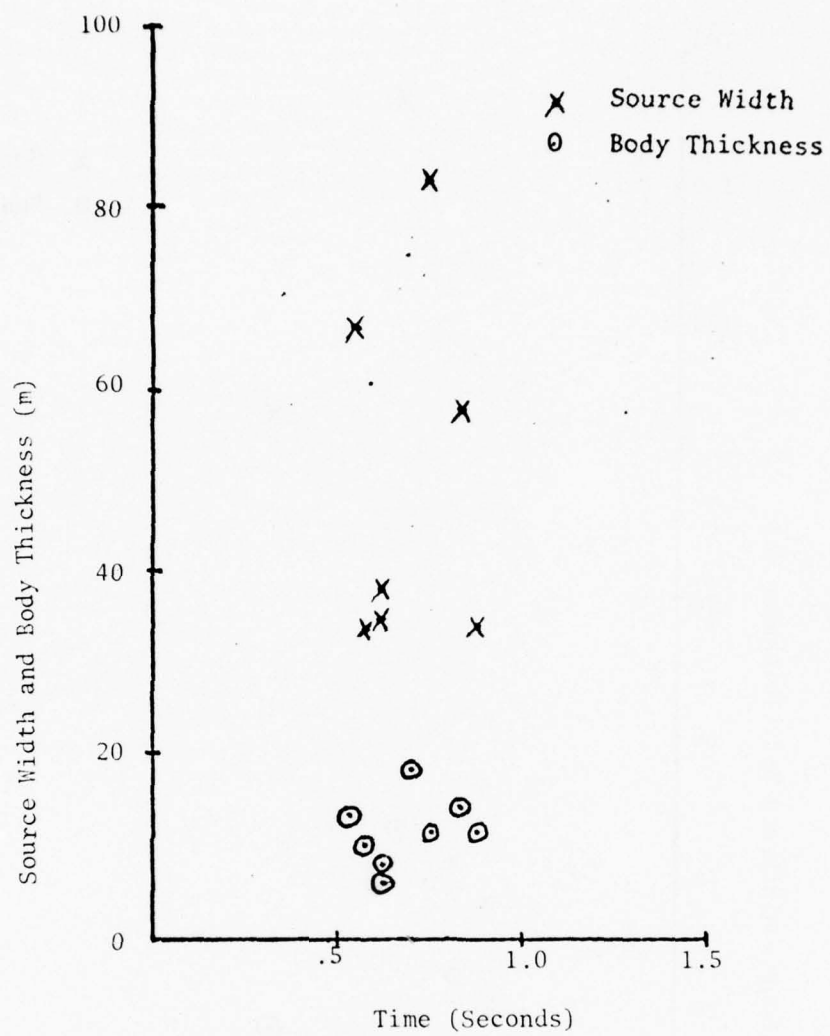


Figure 6. Source Description, 4.2" WP

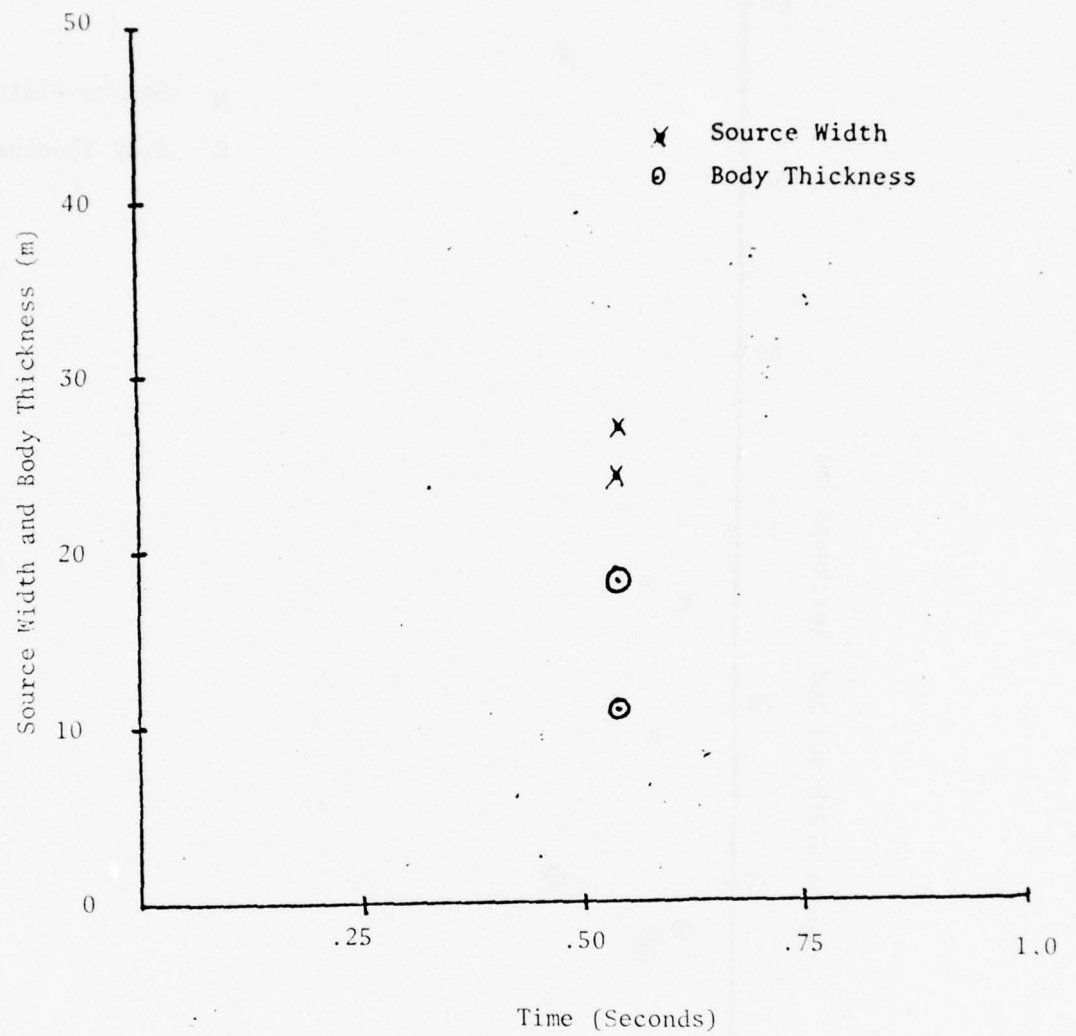


Figure 7. Source Description, 105mm WP

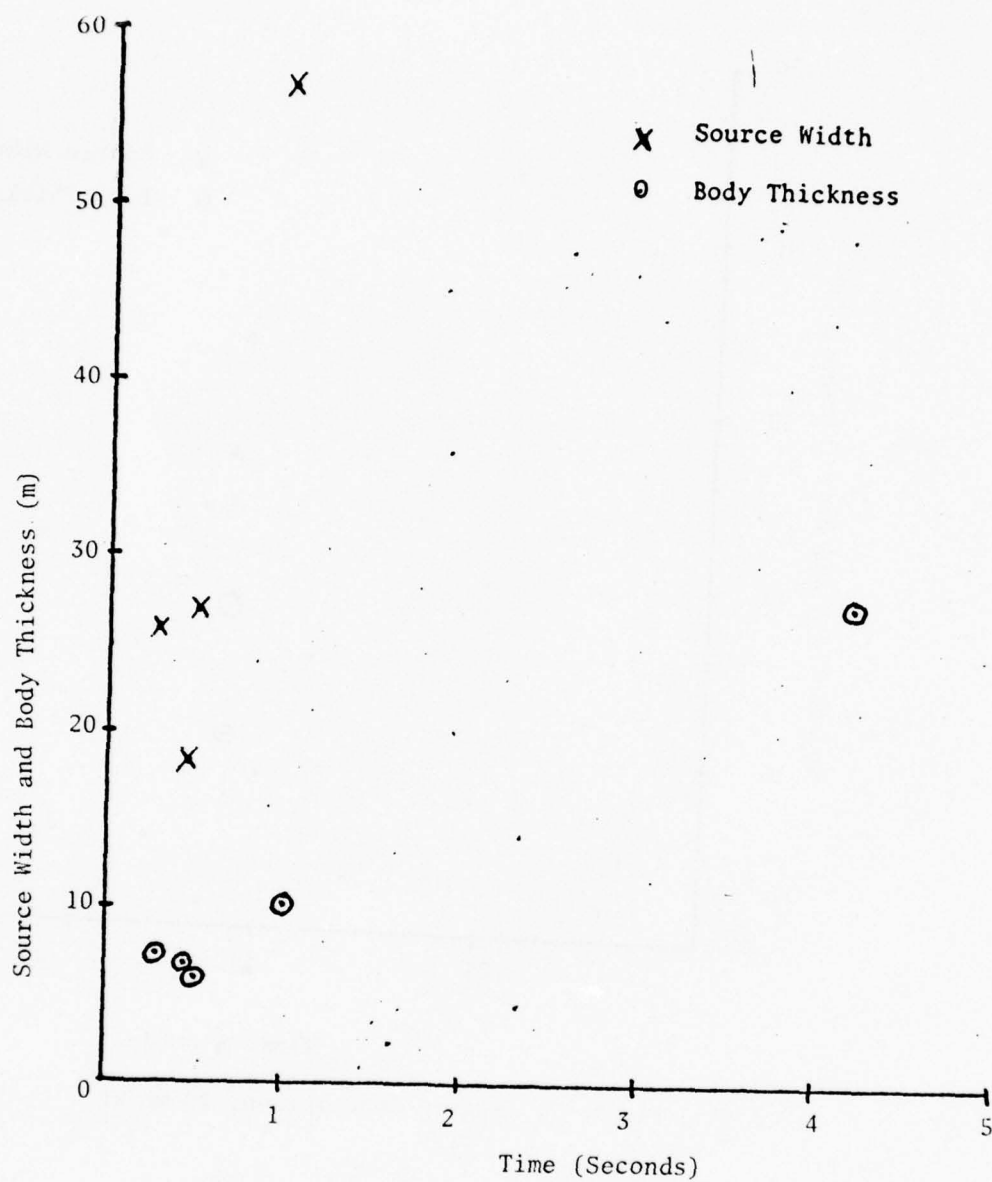


Figure 8. Source Description, 81mm WP



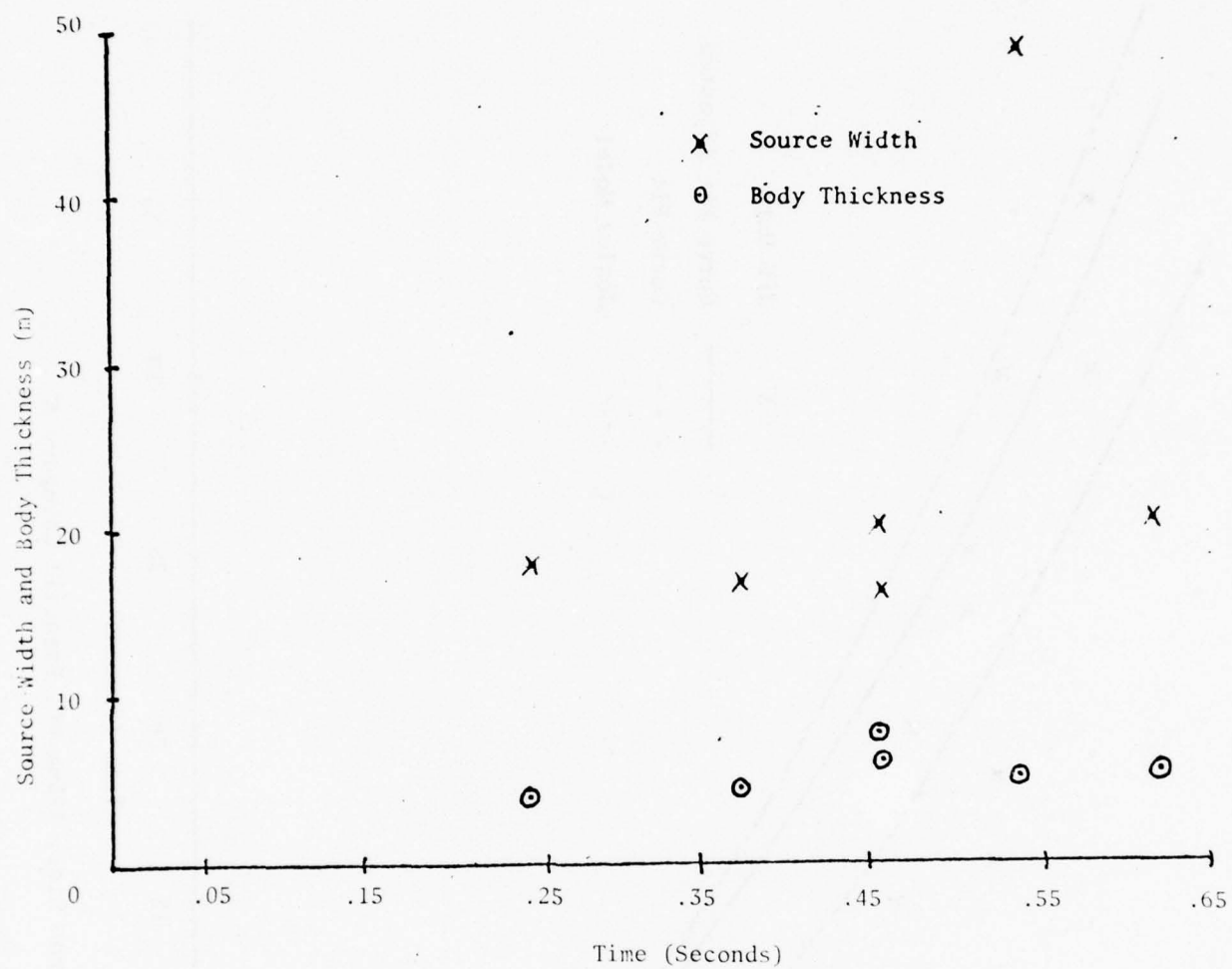


Figure 9. Source Description, 60mm WP

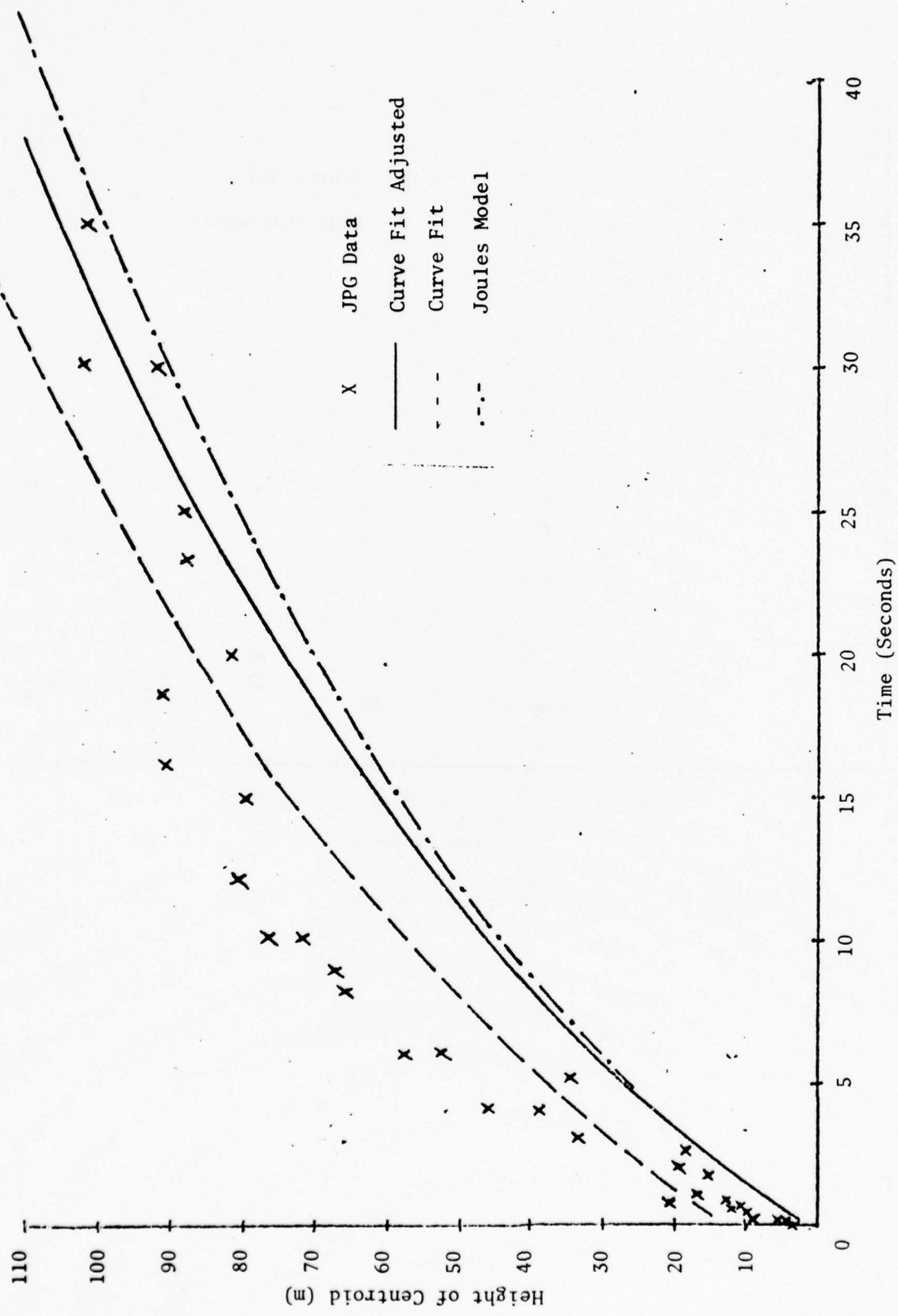


Figure 10. Plume Rise, 155mm WP, Pasquill Category A

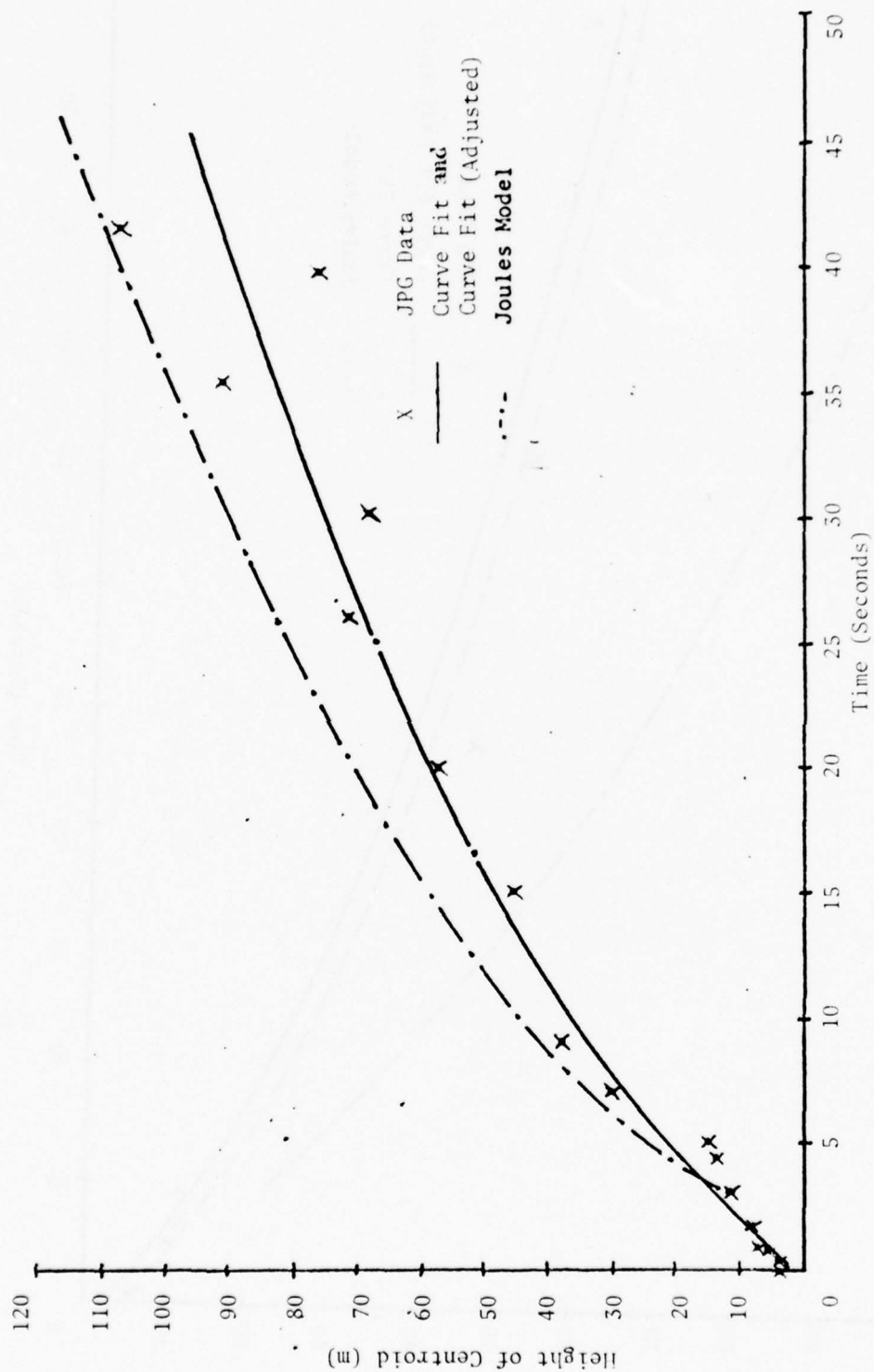


Figure 11. Plume Rise, 155mm WP, Pasquill Category B

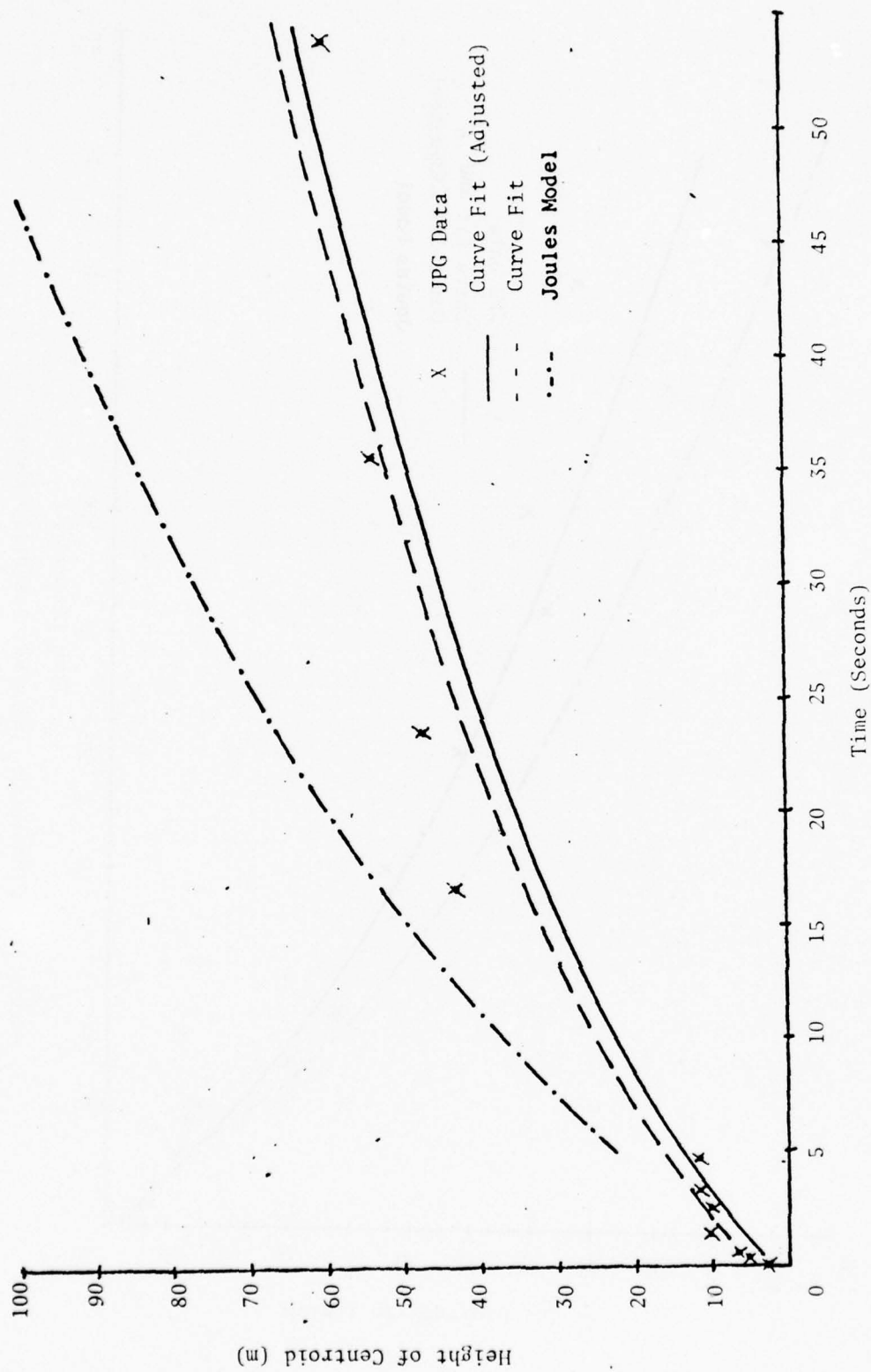


Figure 12. Plume Rise, 155mm WP, Pasquill Category C

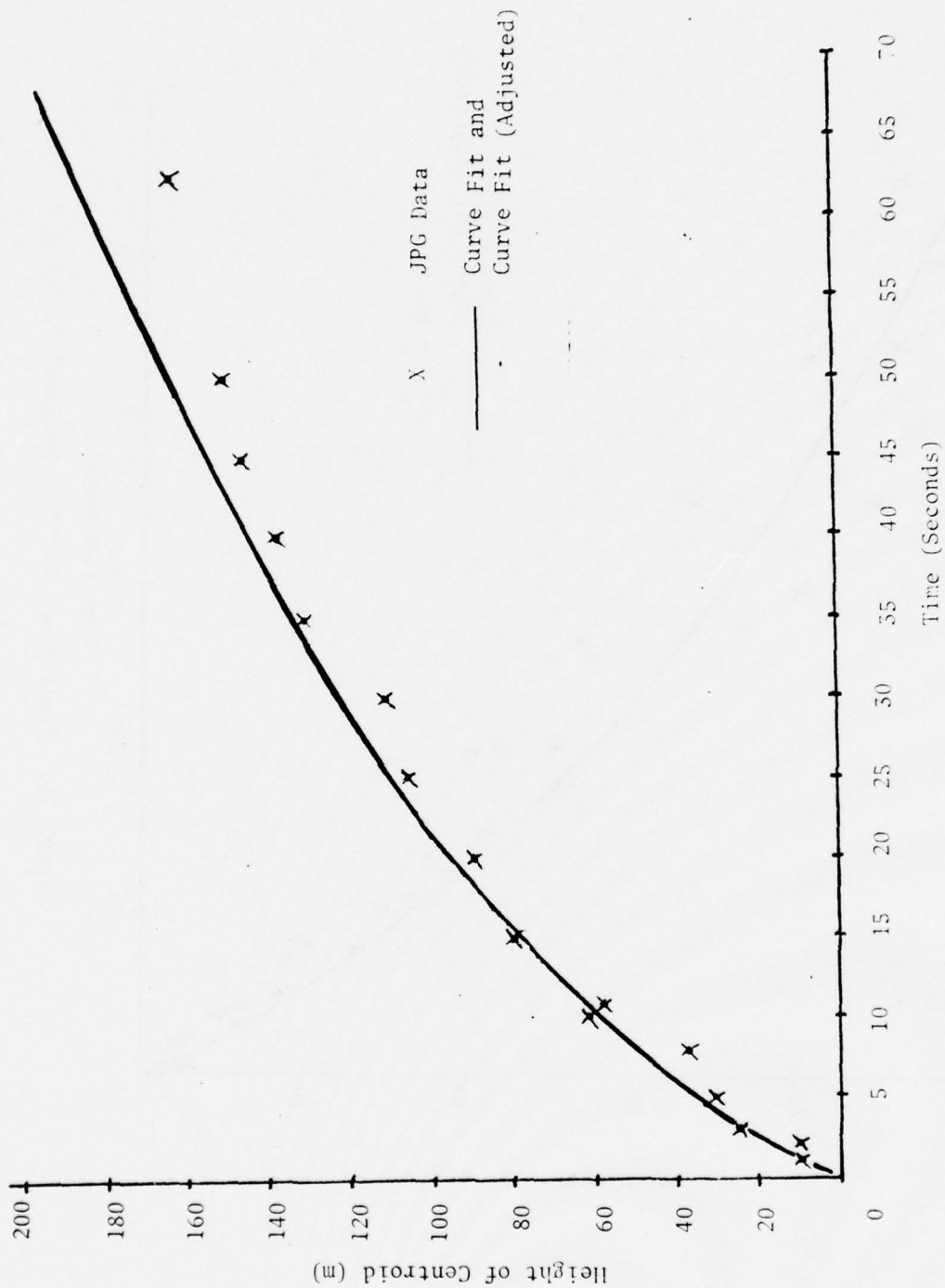


Figure 13. Plume Rise, 4.2" WP, Pasquill Category A



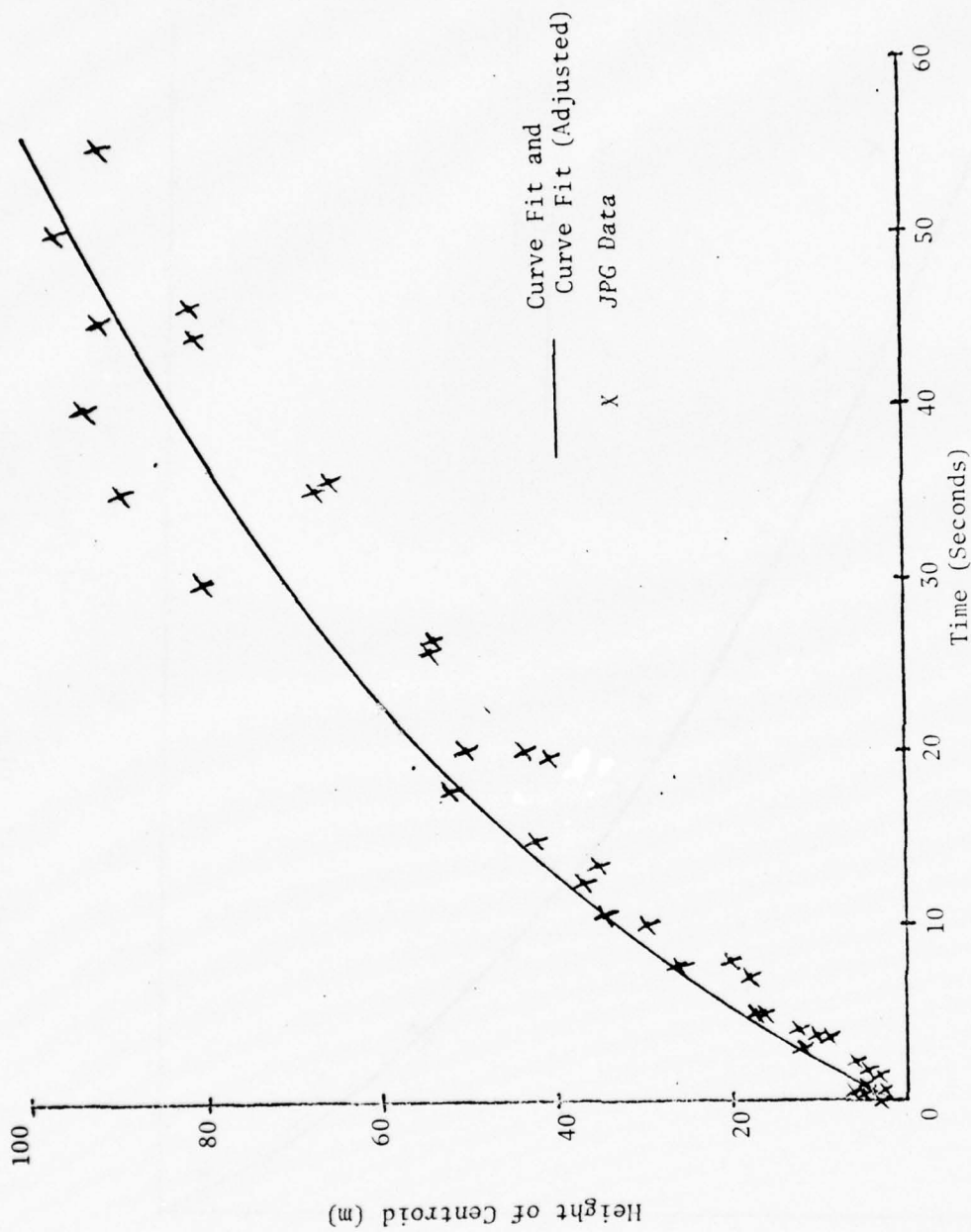


Figure 14. Plume Rise, 4.2" WP, Pasquill Category B

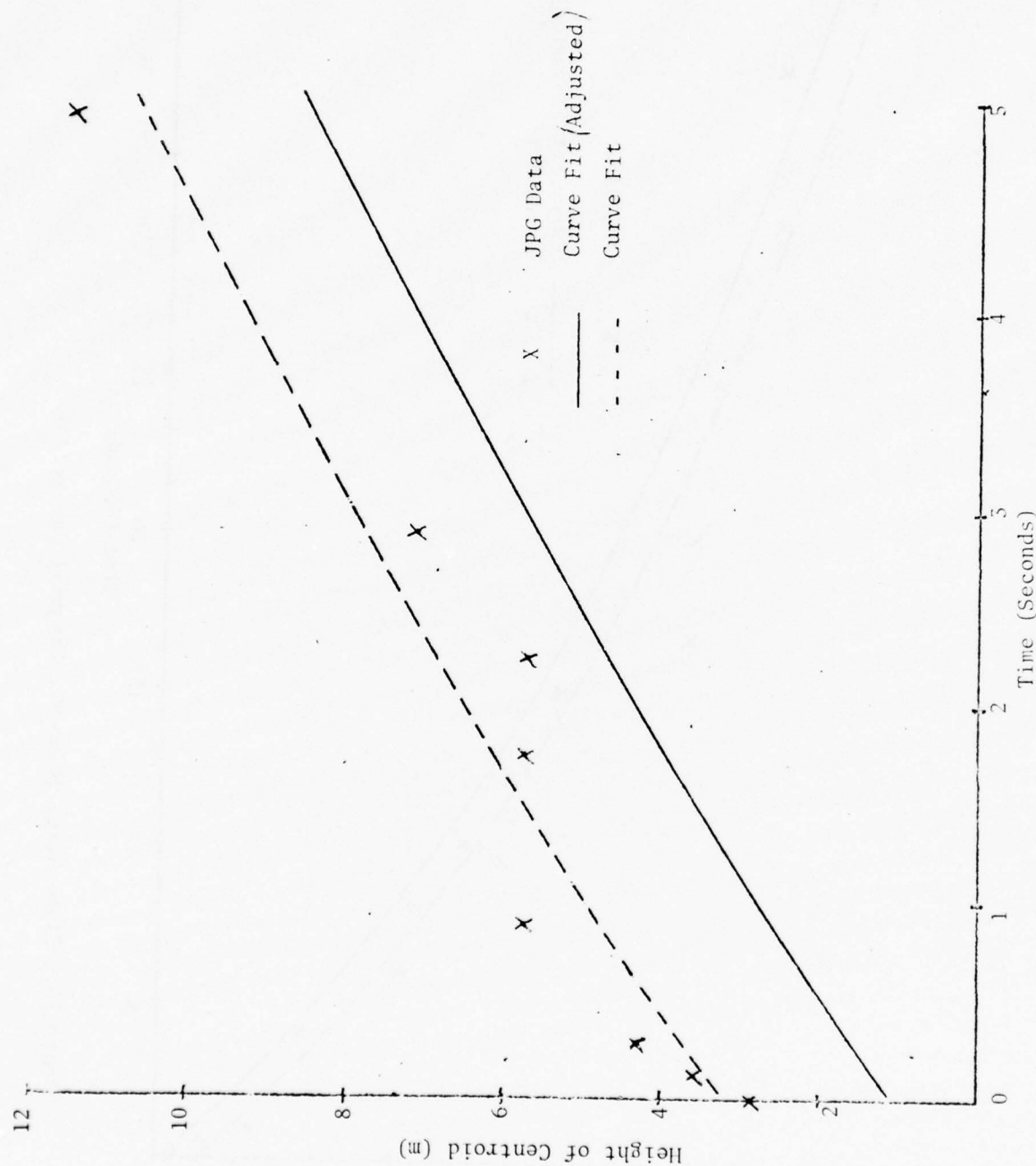


Figure 15. Plume Rise, 4.2" WP, Pasquill Category C

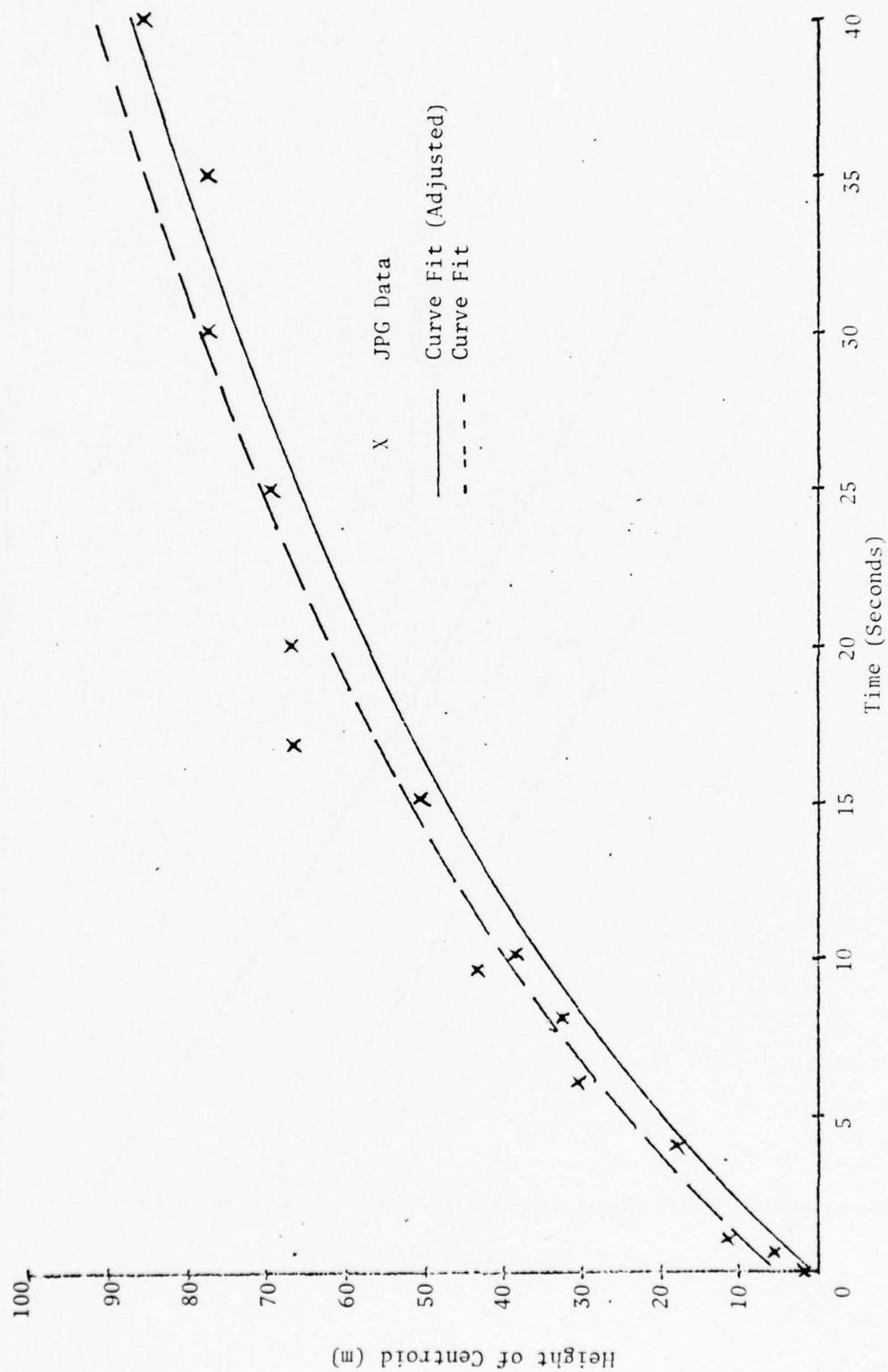


Figure 16. Plume Rise, 105mm WP, Pasquill Category A

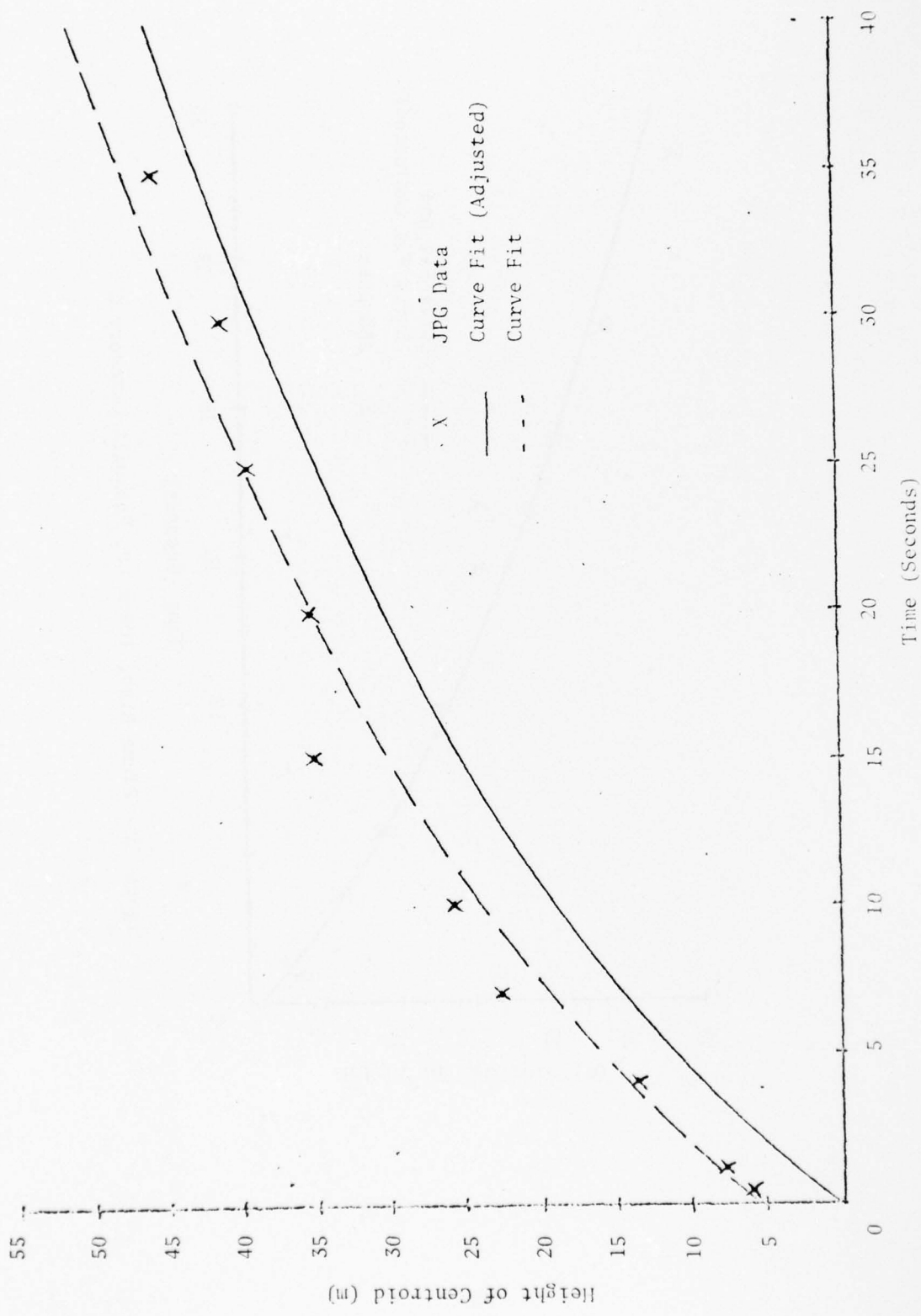


Figure 17. Plume Rise, 105mm EP, Pasquill Category B

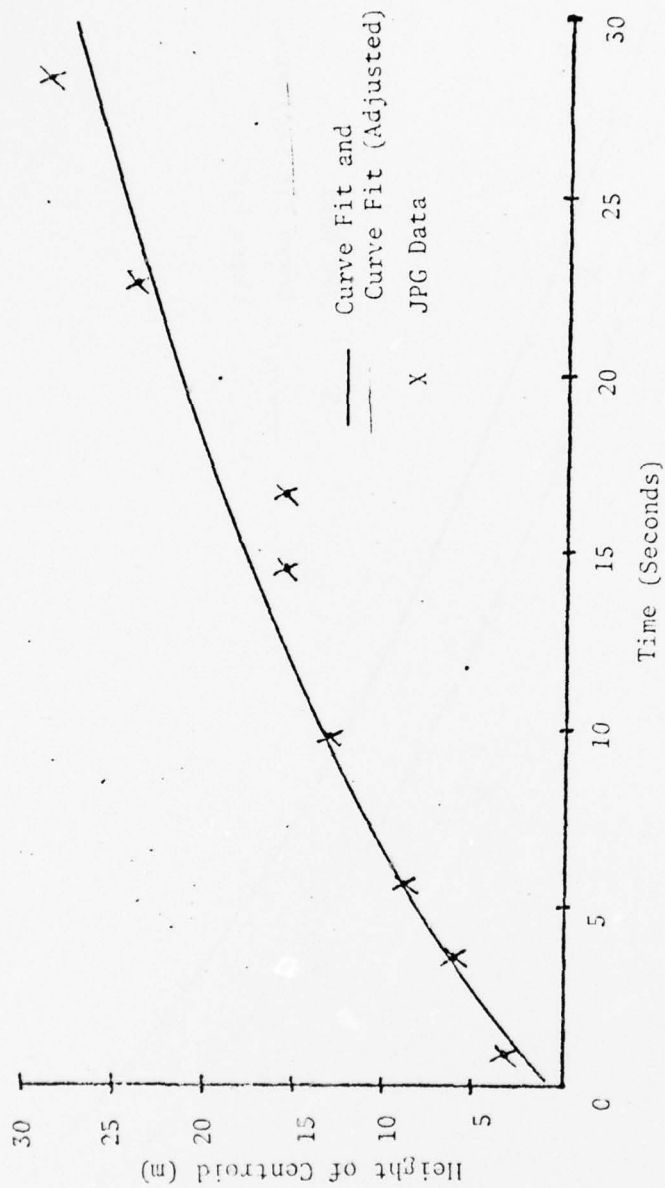


Figure 18. Plume Rise, 105mm WP, Pasquill Category C



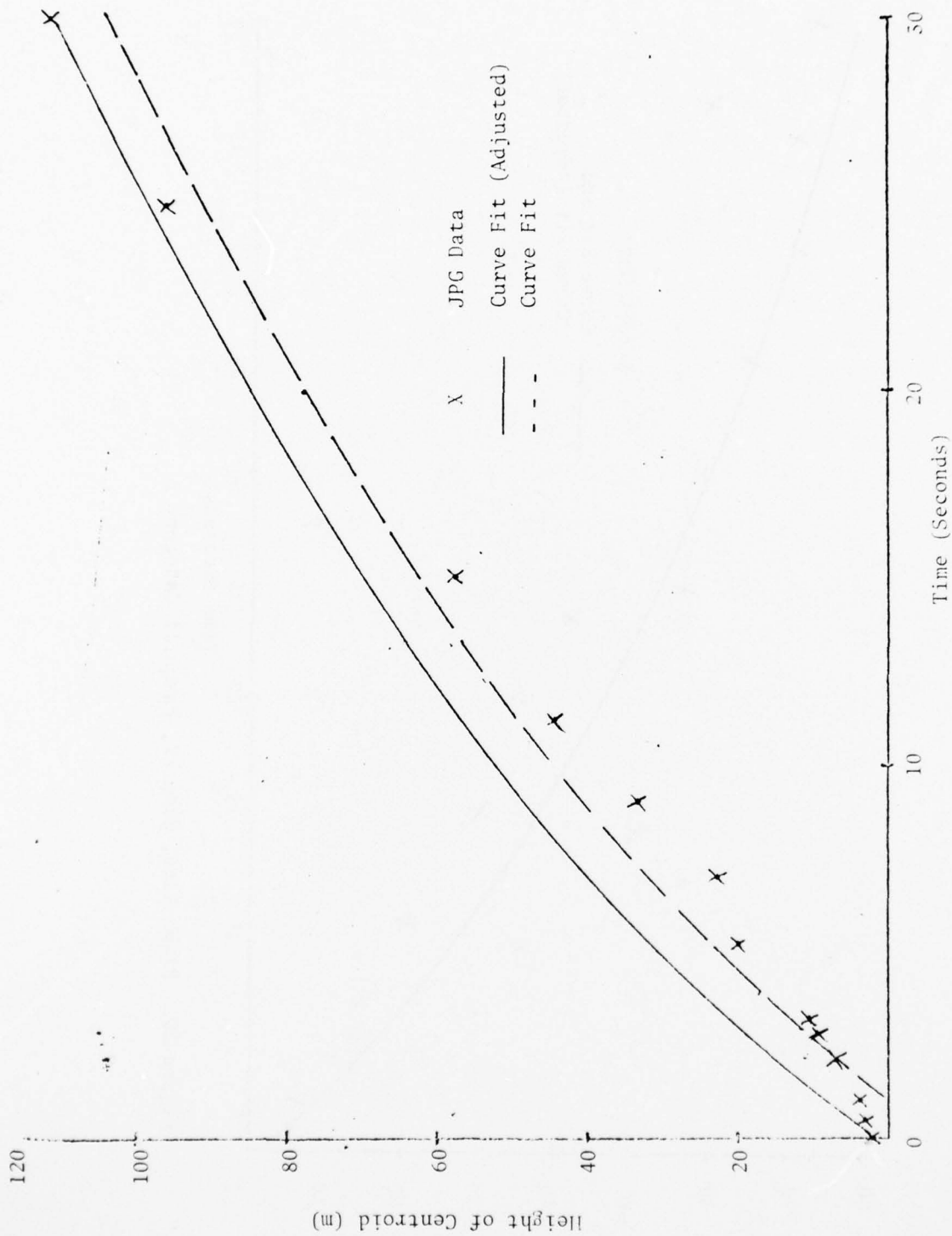


Figure 19. Plume Rise, 8mm WP, Pasquill Category A

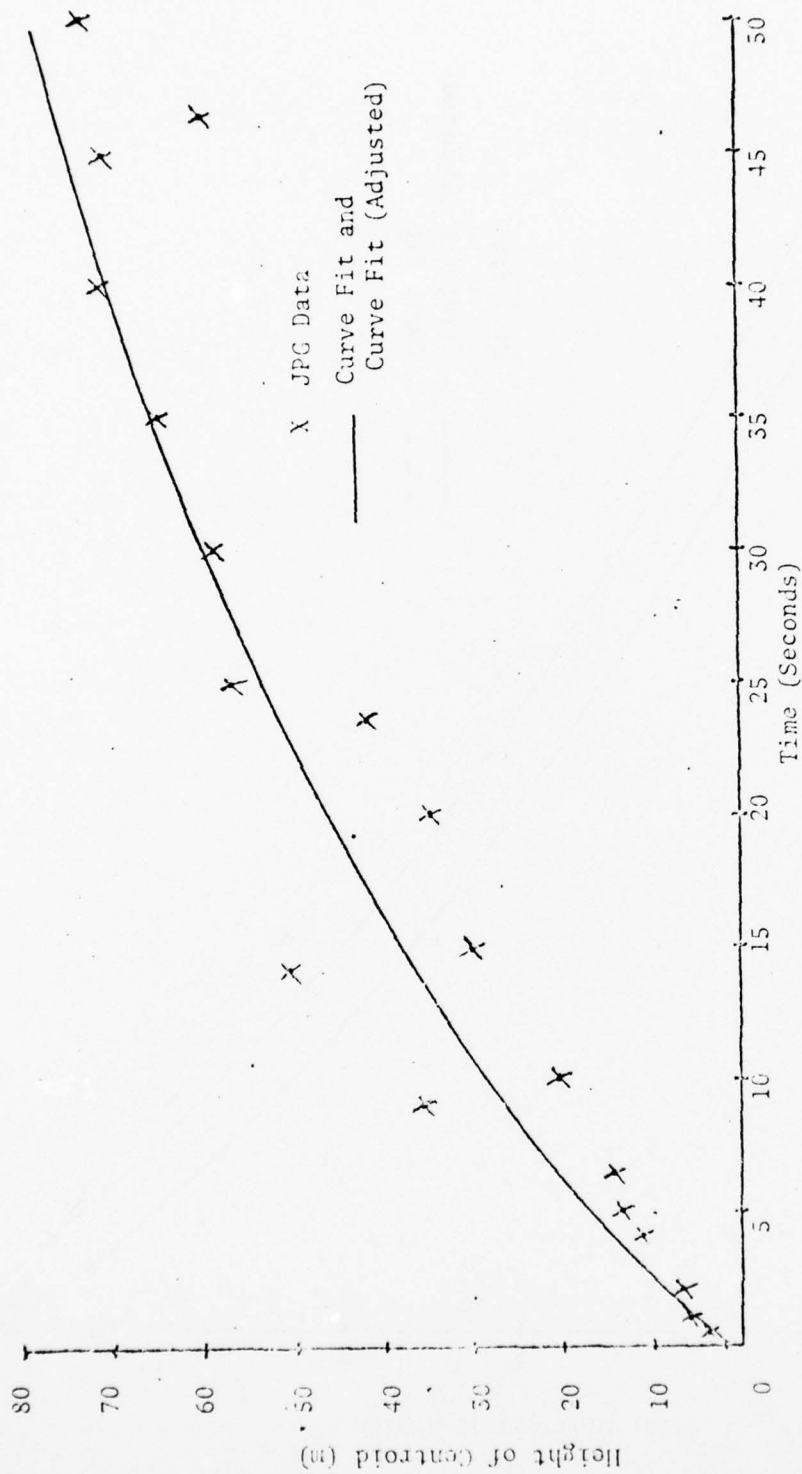


Figure 20. Plume Rise, 81mm WP, Pasquill Category B

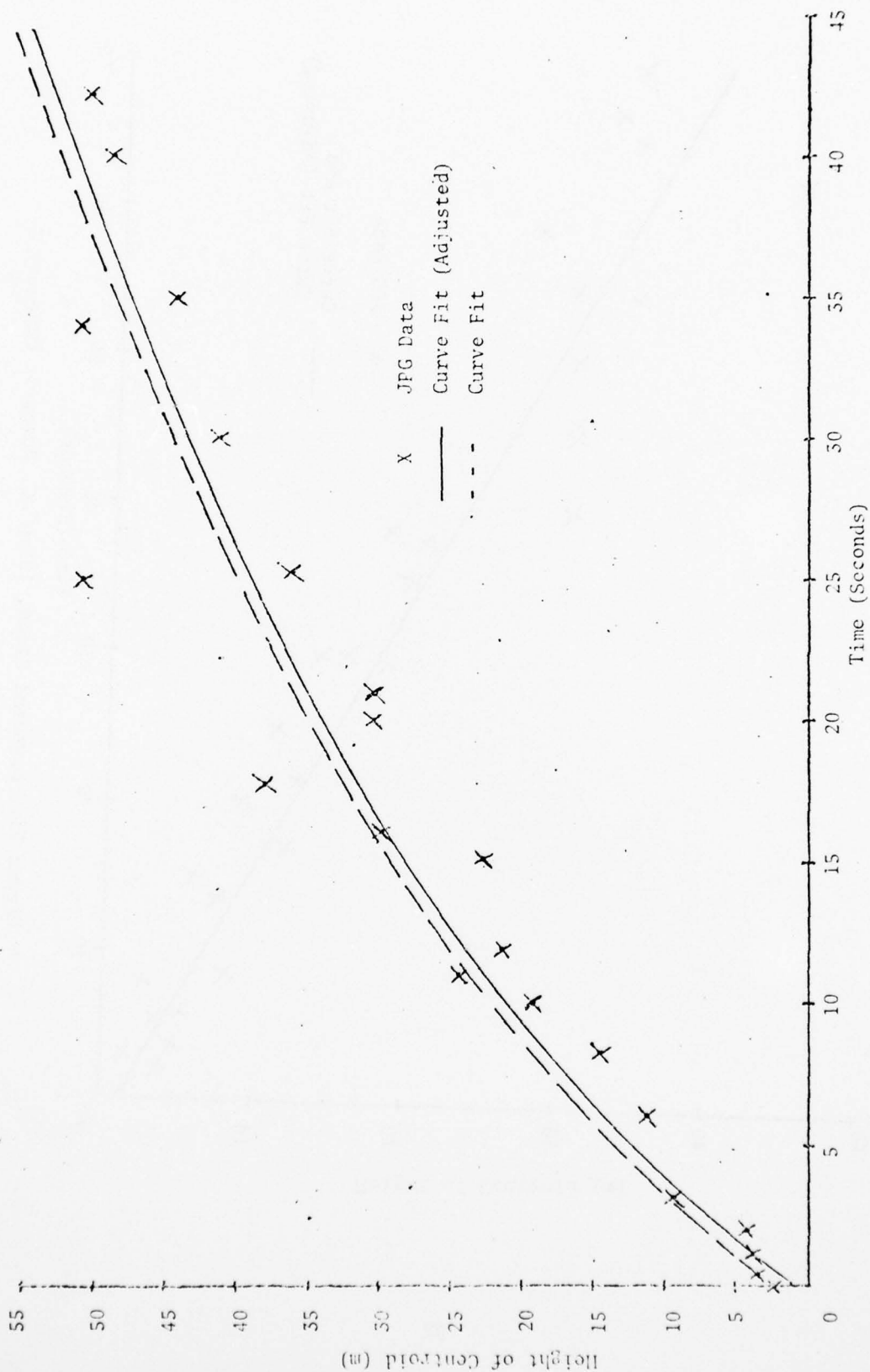


Figure 21. Plume Rise, 60mm WP, Pasquill Category B

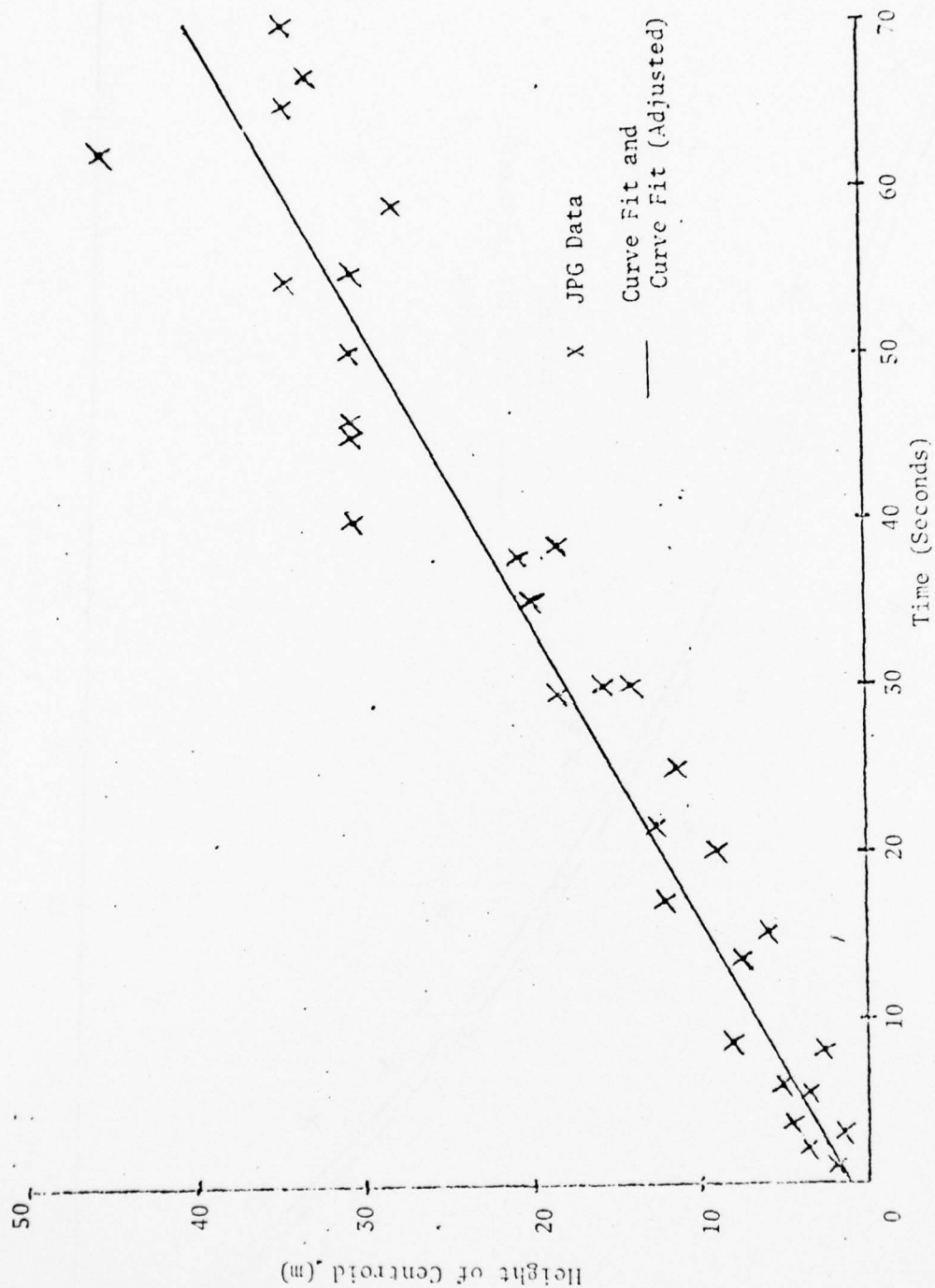


Figure 22. Downwind Cloud, 155mm i/C, Pasquill Category 3

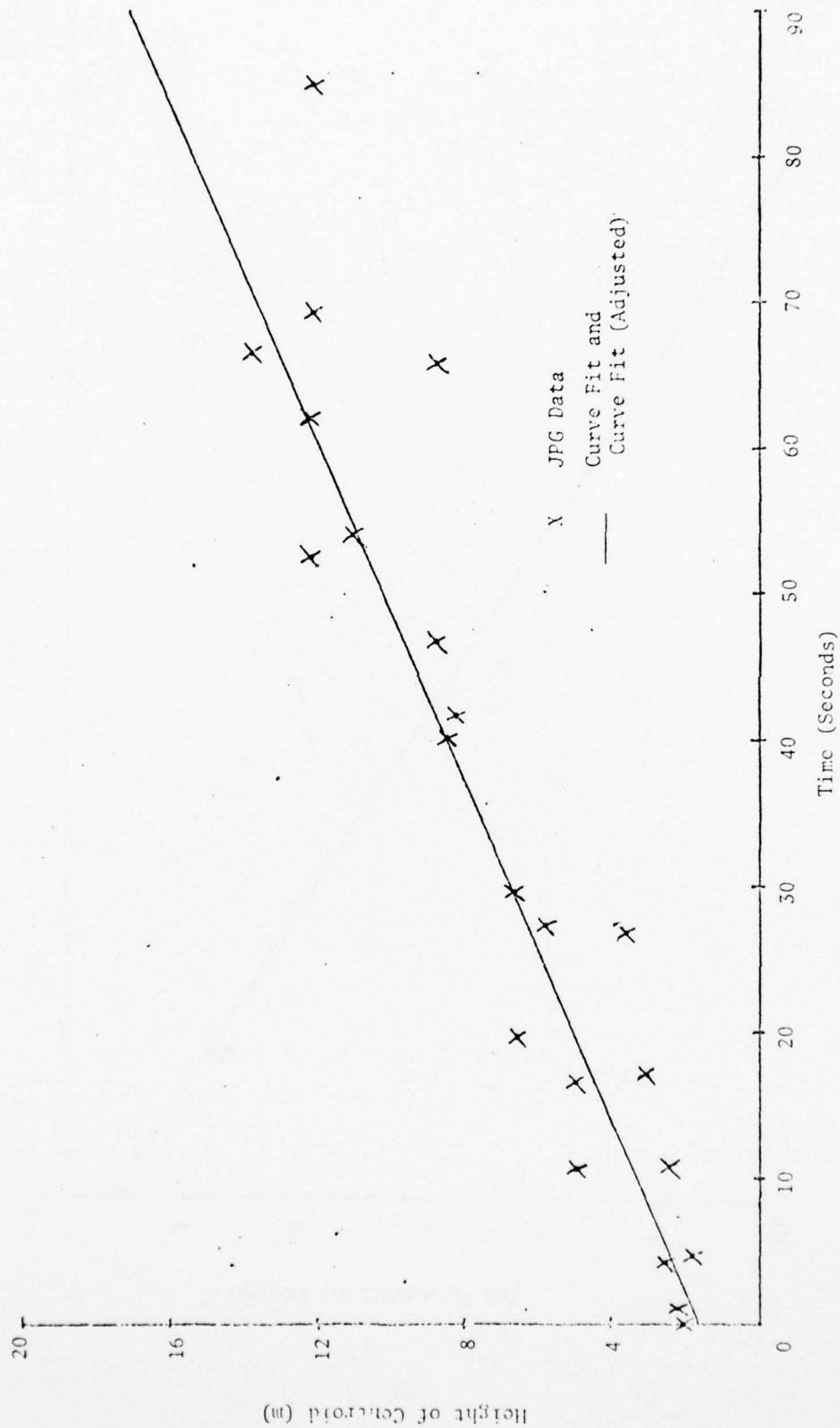


Figure 23. Downwind Cloud, 155mm H<sub>2</sub>O, Pasquill Category C



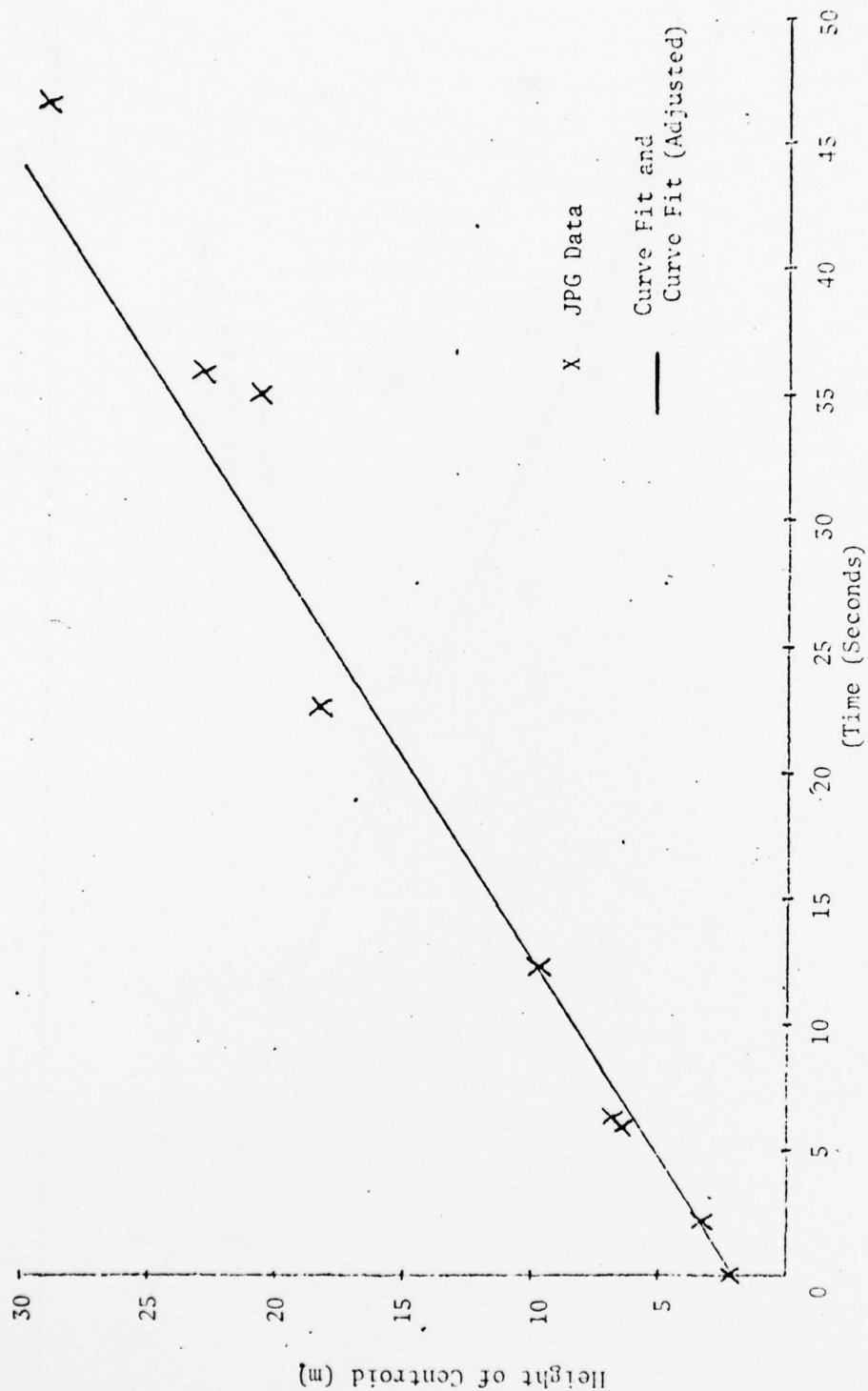


Figure 24. Downwind Cloud, 105mm iC, Pasquill Category A

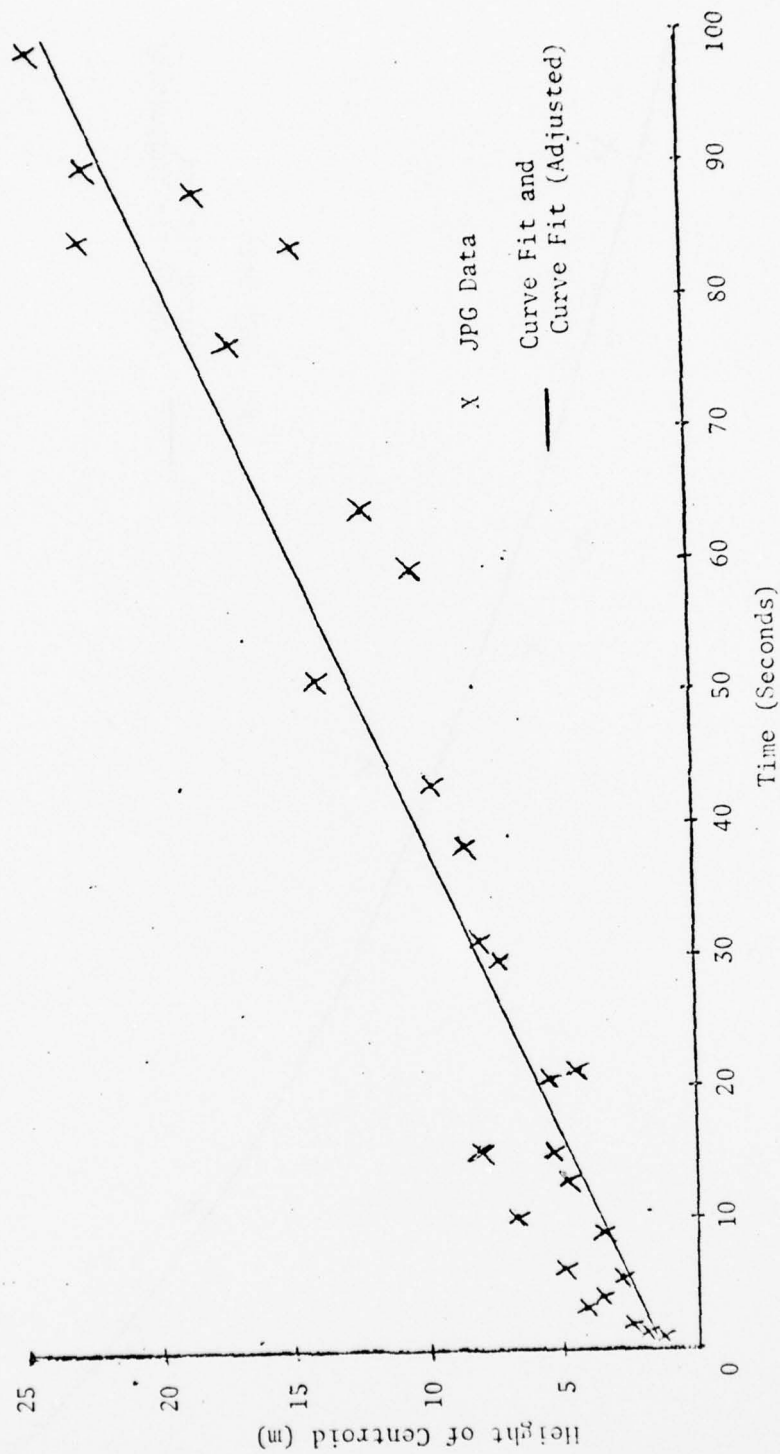


Figure 25. Downwind Cloud, 105mm, Pasquill Category E

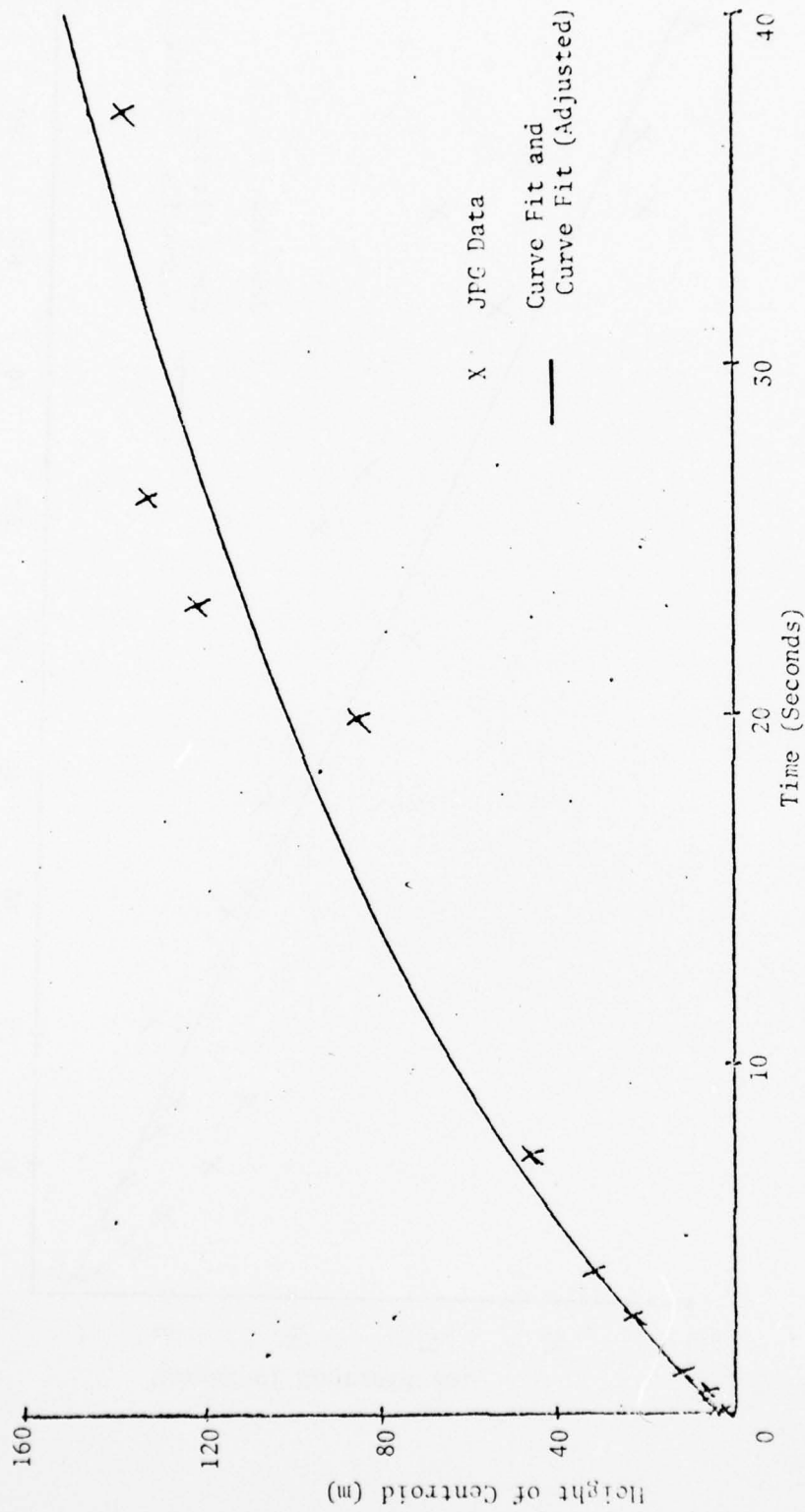


Figure 26. Plume Rise, 4.2" WP, Static Firing

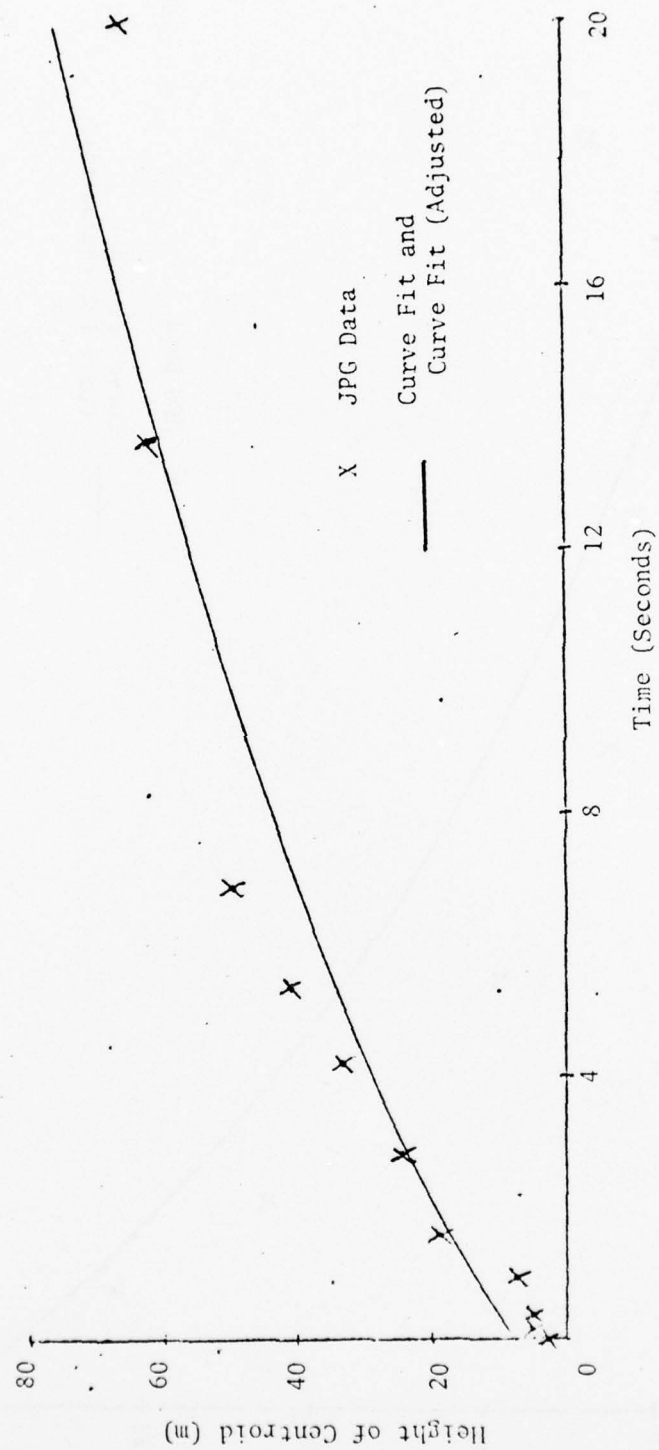


Figure 27. Plume Rise, 105mm WP, Static Firing

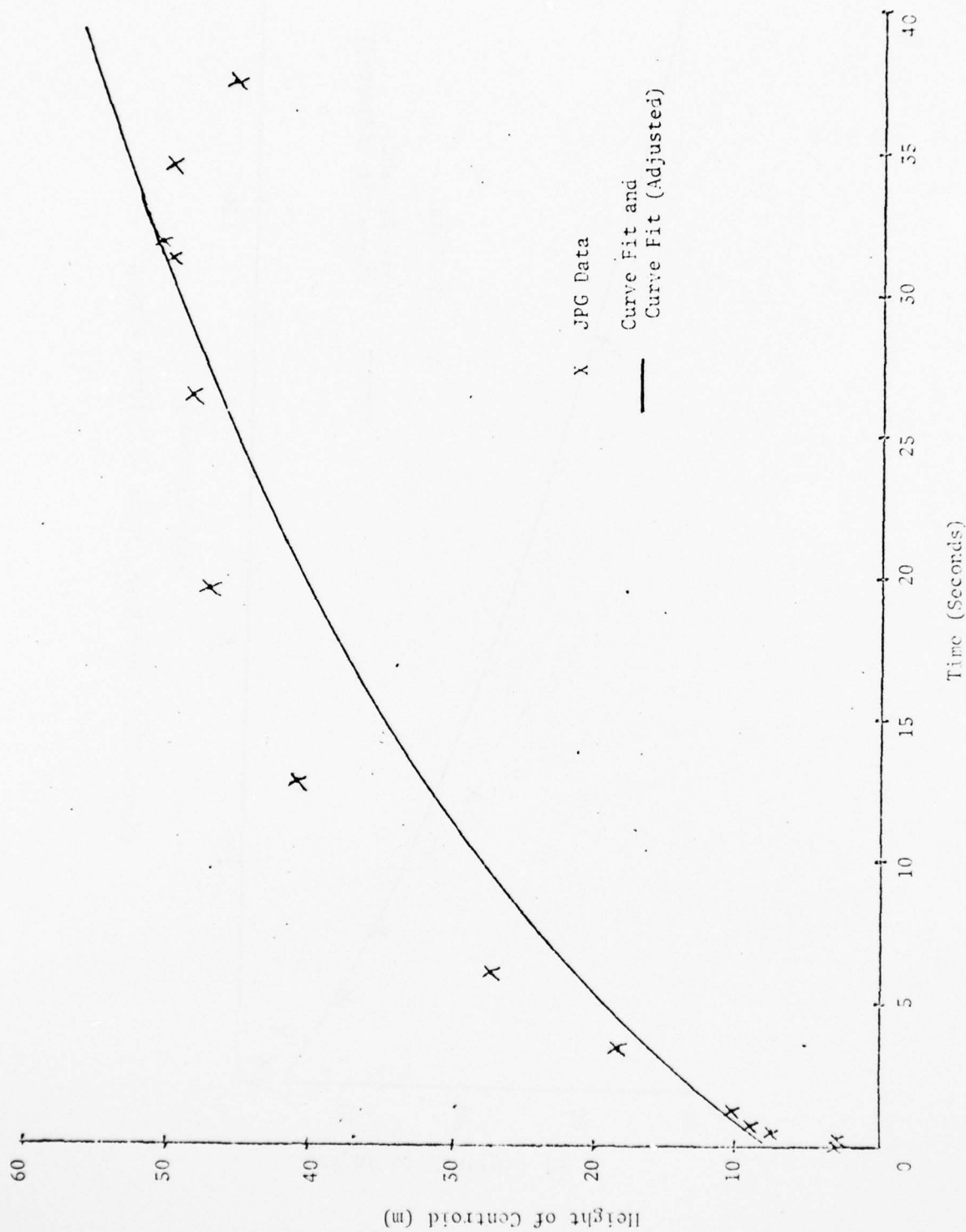


Figure 28. Plume Rise, 8mm WP, Static Firing



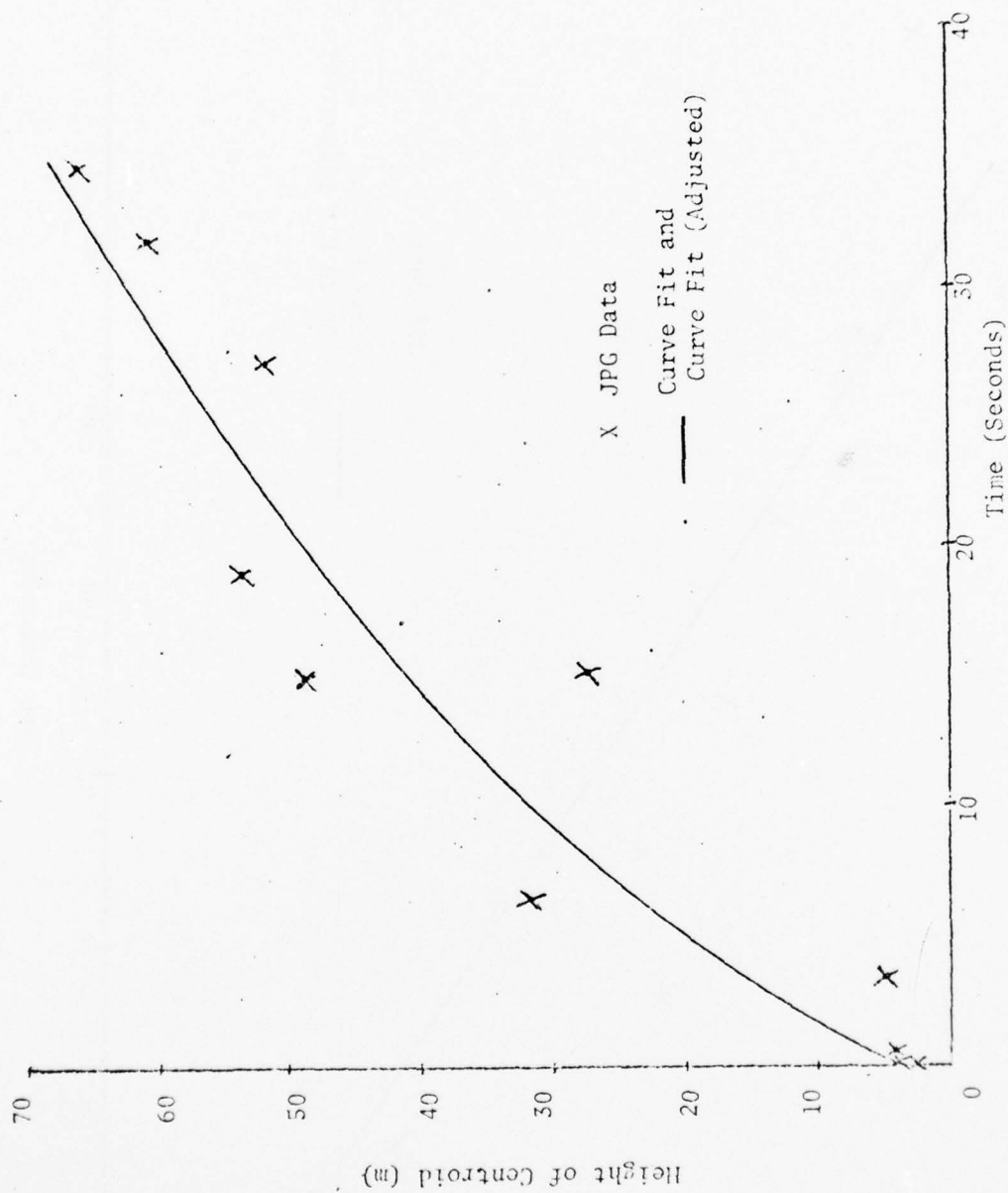


Figure 29. Plume Rise, 60mm WP, Pasquill Category Static Firing

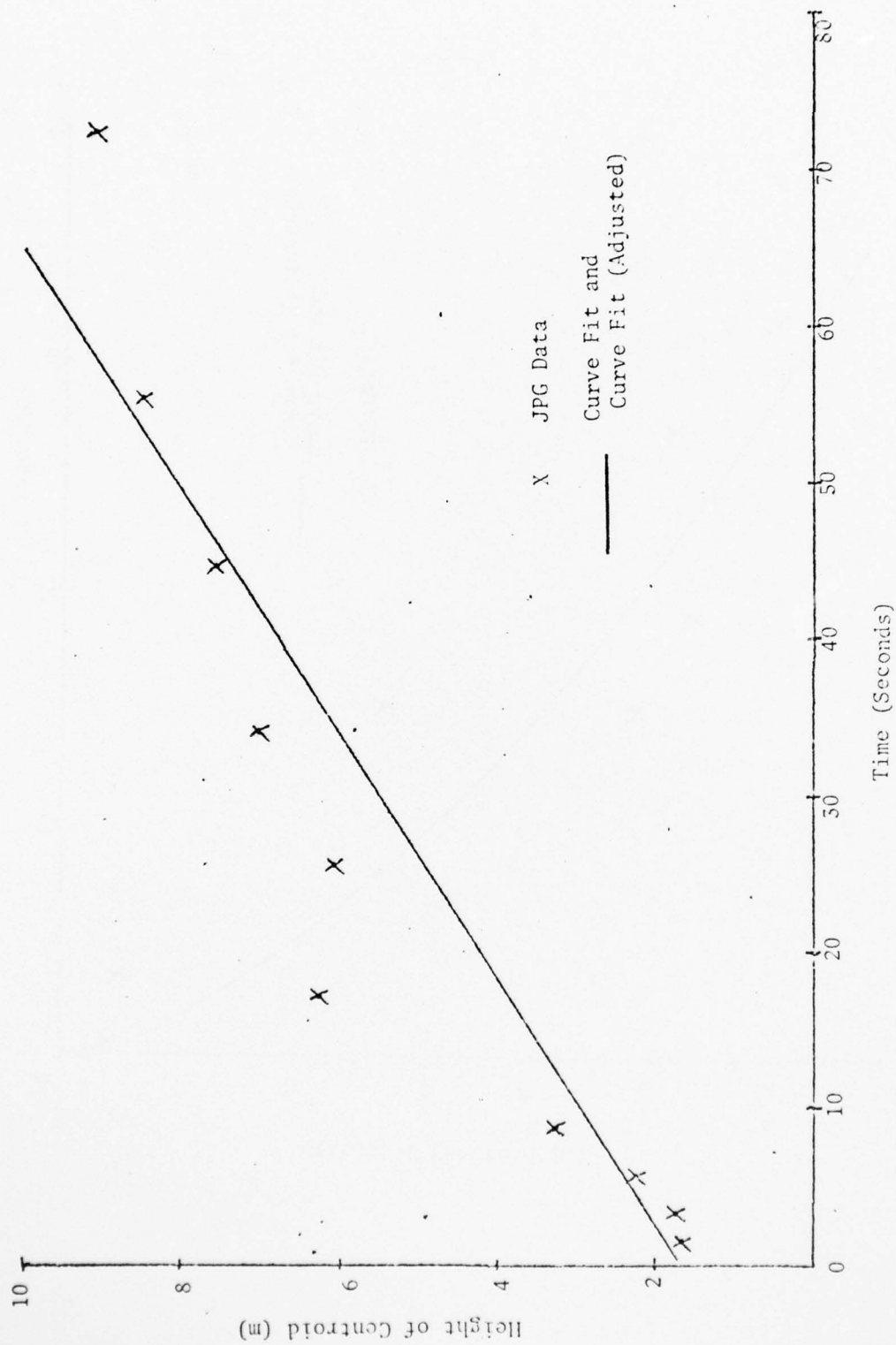


Figure 30. Downwind Cloud. 155mm HC, Pasquill Category, Static Firing

APPENDIX C. JOULES CLOUD RISE MODEL

Next page is blank

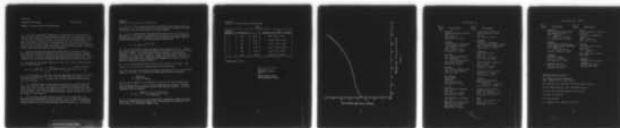
AD-A045 874

ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY ABERDEEN PROV--ETC F/G 19/1  
AN ANALYSIS OF THE SMOKE CLOUD DATA FROM THE AUGUST, 1975 JEFFE--ETC(U)  
SEP 77 T J DOLCE, D F METZ  
AMSAA-TR-201

UNCLASSIFIED

NL

2 of 2  
ADA045874



END  
DATE  
FILMED  
11-77  
DDC

28 April 1975

SUBJECT: Vertical Rise of a Heated Plume

1. This "first-generation" methodology for computing the rate-of-rise of a heated plume has been developed from first principles. The assumption is made that the plume resembles an oblate spheroid with a well-defined initial volume. The contents of the plume are "hot", with respect to its surrounding air mass. Thus, the density of the plume is less than the air, and the plume tends to lift because of bouyant forces. As energy is lost through the plume's surface, bouyant forces are reduced and the plume's rate of ascent decreases. Expansion of the plume with time complicates the methodology.

2. Empirical data from the 1971 Yuma Proving Ground surveillance tests of the 155MM, M110 series, WP projectile were used to evaluate certain constants which appear in the model. Because those tests were not intended to provide technical data, certain constants are specified with little confidence. Those constants will be subject to change as more definitive data become available.

3. The height of the plume's centroid, at any time  $t$ , may be calculated from the following equation:

$$z(t) = z_0 + \left(\frac{\psi t}{n}\right) \lim_{n \rightarrow \infty} \sum_{i=1}^n \left\{ \frac{(M-1)T_{i-1} + (\tau_{i-1} - T_{i-1}) Me^{k \int_{i-1}^i f(t)} \right\}^{0.7} \\ T_{i-1}$$

4.  $z_0$  is the height of the plume's centroid immediately after munitions impact and smoke dissemination (i.e.,  $t=0$ ). For WP ammunition the volume at  $z_0$  is calculated from  $z_0 = 3\sigma_{zs}$ . In particular, for the 155MM WP round the value of  $z_0$  is 7.0 meters.

5.  $\psi$  is a constant which has been derived, empirically, from the Yuma test data. Its numerical value is believed to depend upon atmospheric stability conditions, only. However, that assumption remains to be validated by tests of WP ammunition other than the 155MM projectile. In the interim, the  $\psi$  values shown in Table 1, one for each Pasquill stability category, should be used in the height of rise equation.

6.  $n$  is the number of equal intervals into which the elapsed time (i.e., measured from dissemination at  $t=0$ ) is divided. It is usually not economical to use a large  $n$  unless the true lapse rate is known in detail. In practice, one-second intervals from  $t=0$  to the final time of interest,  $t_f$ , are adequate.



AMSAR-SAM

SUBJECT: Vertical Rise of a Heated Plume

7.  $T_i$  is the virtual temperature ( $^{\circ}\text{K}$ ) of the ambient air at the end of the  $i$ th interval. As the plume ascends the ambient temperature changes according to the true lapse rate, pressure and relative humidity.

8.  $\tau_i$  is the corresponding temperature of the plume ( $^{\circ}\text{K}$ ) at the end of the  $i$ th interval. The value of  $\tau_i$  depends upon the rate of heat loss through the surface area of the plume, which, in turn, is related to the volume occupied by the expanding plume.  $\tau_i$  is calculated from the equation.

$$\tau_i = (\tau_{i-1} - T_{i-1}) e^{k \int_{i-1}^i f(t) dt}$$

9.  $f(t)$  is the surface area of the plume (square meters) at time  $t$ . Since the volume occupied by the plume increases at a different rate for each Pasquill stability category, the surface areas are also dependent upon atmospheric stability.  $f(t)$  are shown in Table 1. Those  $f(t)$  apply only to the first 20 seconds of elapsed time. Additional efforts are being made to characterize  $f(t)$  as a simple power-law relationship with elapsed time, rather than the quadratic relationships shown in Table 1.

10.  $k$  is a constant associated with the rate of cooling of the plume. The value,  $k = -2.9 \times 10^{-5}$ , was inferred from the Yuma test data.

11.  $M$  is the ratio of the molecular weight of the ambient air to the molecular weight of the plume. Its value can be calculated from the relationship

$$M = \frac{4533 T_o \rho_o}{\tau_o (1.5 + 3626 \rho_o)}$$

where  $\rho_o$  is the density of air ( $\text{kg/m}^3$ ) at  $z_o$ ;  $T_o$  is the virtual temperature ( $^{\circ}\text{K}$ ) of the air at  $z_o$ ;  $\tau_o$  is the initial temperature of the plume, dependent upon the ambient air temperature, pressure and relative humidity.  $\tau_o$  can be calculated from the equation

$$\tau_o = 273 + \frac{7680(1+\lambda) + T'_o (1.5 + 871.79 \rho_o)}{1.5 + 871.79 \rho_o}$$

12.  $\lambda$  is the yield factor to be obtained from the empirical graph of Relative Humidity vs Yield Factor (see Fig 1);  $T'_o$  is the ambient air temperature ( $^{\circ}\text{K}$ ) at  $z_o$ ; and  $\rho_o$  is the density ( $\text{kg/m}^3$ ) at  $z_o$ .

AMSAR-SAM

SUBJECT: Vertical Rise of a Heated Plume

TABLE 1

PASQUILL's CATEGORY	PROBABILITY	$\psi$	$f(t)$ (GOOD FOR ONLY FIRST 20 SECONDS)
A	50%	13.25	$60t^2 + 350t + 1407$
B	50%	10.75	$8.61t^2 + 228t + 1407$
C	50%	8.90	$5.1t^2 + 192t + 1407$
D	50%	7.45*	$4.8t^2 + 130t + 1407^*$
E	50%	6.15*	$4.6t^2 + 93t + 1407^*$
F	50%	4.95*	$4.5t^2 + 67t + 1407^*$

\*extrapolated values

*Reginald G. Joules*  
REGINALD G. JOULES  
SP/5

Methodology Division  
Systems Analysis Office

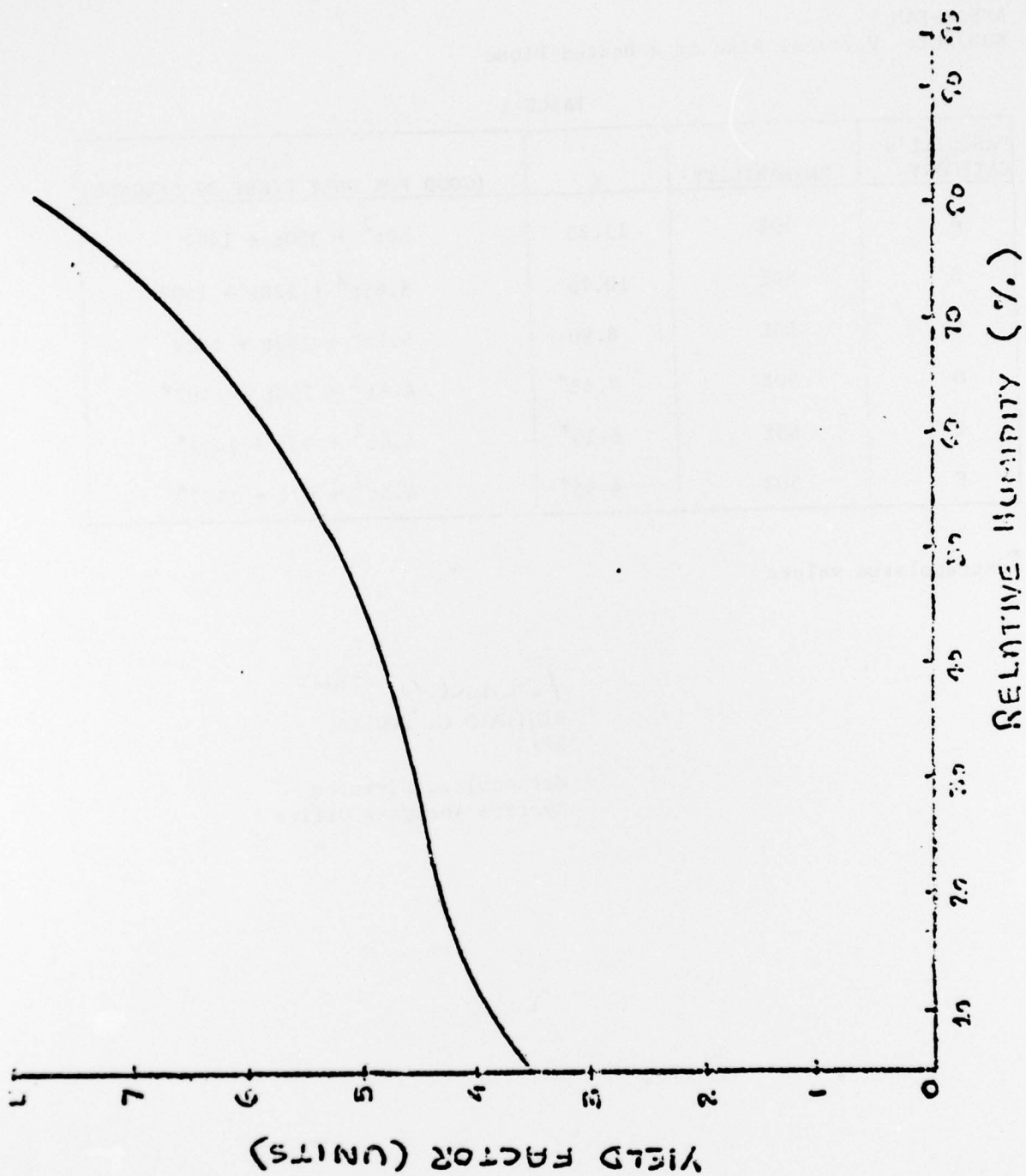


FIG. 2

# DISTRIBUTION LIST

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
12	Commander Defense Documentation Center ATTN: TCA Cameron Station Alexandria, VA 22314	1	Science Applications, Inc. ATTN: Frederick G. Smith Box 328 Ann Arbor, MI 48107
1	Commander US Army Materiel Development and Readiness Command ATTN: DRCPA 5001 Eisenhower Avenue Alexandria, VA 22333	1	Commander USA Mobility Equipment Research & Development Command ATTN: DRXFB-RCT (Fred Kezer) Fort Belvoir, VA 22060
1	Commander Harry Diamond Laboratories ATTN: DRXDO-RAF (Mr. Dominick Giglio) 2800 Powder Mill Road Adelphi, MD 20783	1	Commander Naval Weapons Center Code 385 ATTN: Russell Reed, Jr China Lake, CA 93555
1	Commander Naval Weapons Support Center ATTN: Mr. Duane Johnson Crane, IN 47522	1	Martin-Marietta Corporation P.O. Box 5837 ATTN: William A. Buss Orlando, FL 32805
1	The Pentagon ODDR&E (E&PS) Rm 3D1079 ATTN: Thomas Walsh Washington, DC 20301	1	Teledyne Brown Engineering ATTN: James C. Majure Huntsville, AL 35807
1	Director Naval Research Laboratory Code 5709 ATTN: Mr. Wm E. Howell Washington, DC 20375	1	Director Night Vision Laboratory ATTN: DRSEL-NV-VI (Richard J. Bergemann) Fort Belvoir, VA 22043
1	Lockheed Missiles and Space Co., Inc. Huntsville Res & Eng Center ATTN: Mr. L. Ray Baker 4800 Bradford Drive Huntsville, AL 35804	1	Oklahoma State University School of Technology ATTN: Dr. Marvin D. Smith Stillwater, OK 74074
		1	RAND ATTN: John K. Walker, Jr. 2100 M. St., NW Washington, DC 20037



# DISTRIBUTION LIST (CONT)

<u>No. of Copies</u>	<u>Organization</u>	<u>No. of Copies</u>	<u>Organization</u>
1	Commander US Army Combined Arms Combat Developments Activity ATTN: ATCA-COA (Robert A. Davidson) Fort Leavenworth, KS 66027	2	Chief Defense Logistics Information Exchange USA Logistics Management Center ATTN: DRXMC-D Fort Lee, VA 23801
1	Commander US Army Missile Research and Development Command (MIRADCOM) ATTN: DRDMI-CGA (Dr. Bruce Fowler) Redstone Arsenal, AL 35809	2	Director USA TRADOC Systems Analysis Activity ATTN: ATAA-SA ATAA-T White Sands Missile Range, NM 88002
1	Commander Frankford Arsenal ATTN: Dr. Ed Stubing Philadelphia, PA 19124	1	Commander US Army Concepts Analysis Agency 8120 Woodmont Avenue Bethesda, MD 20014
1	<b>Eattelle</b> Institute ATTN: Mr. Milton Cutler Columbus, OH 43216		

## Aberdeen Proving Ground, MD

Dir, Chemical Systems Laboratory,  
ATTN: DRDAB-CLY-A (Mr. Ron Pennsyle)

Cdr, USATECOM, ATTN: DRSTE-ME (Mr. Warren Baity), Bldg 314

PM for Smoke/Obscurants, ATTN: DRCPPM-SMK, Bldg 324

Dir, BRL, ATTN: Warhead Mechanics Div, Bldg 328

Ch, Tech Lib, Bldg 305

Dir, HEL, Bldg 520

Dir. USAMSAA. ATTN: DRXSY-GP (10 Copies)